Statistical Analysis of the Effects of Physical Conditioning on the Fourier Power Spectrum of an EKG Trace

An Honors Thesis (ID 499)

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I. INTRODUCTION

Because of the increasingly heavy patient and work loads which burden doctors, there is a rising awareness of the need for computers in medicine. One area where computers are becoming more prevalent is electrocardiography. Much research is being done in this area and a great deal of literature is becoming available.

One specific area being researched is the study of the daily variations in a person's electrocardiogram (EKG). One study performed in 1972 was designed to determine the normal limits of the day-to-day variability of a normal EKG.[1] A follow-up study was conducted in 1974 to determine the variability of the EKGs of abnormal patients.[2] The 1972 study showed that there were no significant statistical differences between the daily variations of the EKGs for male and female subjects and that the durations of the QRS complex and the P wave were remarkably stable. The 1974 study showed that for twenty patients with hypertension and/or coronary heart disease the variability was not significantly different from that of normal patients; however, patients with heart disease may experience sudden alterations in the conduction of electrical nerve impulses through the heart as shown by sudden conspicuous changes in the EKG patterns of two of the abnormal patients.

In these two studies, computers were invaluable for the storage and analysis of the vast amounts of data. Typically 512 pieces of data were obtained per second per lead for each patient. Data was collected for six seconds over twelve different lead configurations. This was an accumulation of over thirty-six thousand pieces of data per patient per day. It is obvious that the amount of data was too large to be practically analyzed without the use of computers.

Another method of studying EKG data called Fourier analysis has been facilitated by the use of on-line mini-computers. This method was used in 1970 as a way to reduce EKG data to a few stable parameters where variability in these parameters could signal an abnormality.[3]

During the past five years, a number of faculty members in the Ball State University (BSU) Department of Physics and Astronomy have become interested in the laboratory measurements and computer analysis of EKGs. This interest was stimulated by their participation in an adult physical fitness program conducted by the researchers of the BSU Human Performance Laboratory.

One BSU Physics and Astronomy graduate student, Larry McCutchan, conducted his research in the area of the Fourier analysis of electrocardiograms.[4] He analyzed EKG data which had been obtained from the Public Health Service; this included data for ten normal patients and fourteen patients who had an EKG abnormality called ST depression. In this study, McCutchan developed criteria using Fourier components of Lead I EKGs to distinguish the two groups. It was found that the second power spectrum coefficient, c_2, was higher in ST patients than normal patients. From this an ST score was defined as

$$ST_{score} = (P_t \sum_{n=13}^{20} C_n)/(1000C_2)$$

where C_n is the Fourier coefficients and n=0,1,2... P_t represents the total power calculated by summing all the Fourier power spectrum coefficients; C_2 symbolizes the specific Fourier coefficient with n=2. In ST patients, the ST_{score} was lower than in normal patients.

Melinda Brown, an undergraduate at BSU, extended McCutchan's study to determine if McCutchan's criteria were applicable to other lead configurations.[5] It was found that these criteria were effective in the diagnosis of ST depression using leads one, eleven, and twelve.

This investigator continued the research of the Fourier analysis of EKGs during the academic year 1976-77. In this study, it was found that the average of several EKGs smoothed out the fluctuations that occured in a single EKG power spectrum and that the definition of an EKG cycle (R wave to R wave or P wave to P wave) was significant in determining the amplitude of the power spectrum coefficients.[6]

The investigation conducted during the previous year formed a statistical basis for this year's study. In this investigation, Fourier analysis will be used to parameterize EKG data while attempting to observe changes in the Fourier power spectrum as a function of time and conditioning.

II. THE ELECTROCARDIOGRAM

A. Electrical Activity of the Heart

In order for the heart to maintain its coordinated contraction, it has a system of specialized tissue which carries the electrical cardiac impulse. This impulse causes a change in the permeability of the cell membrane so that electrolytes can pass through it. In the resting state, electrolytes are distributed in a manner that causes the inside surface to be negatively charged with respect to the outside. When the cell is stimulated, the membrane becomes permeable to the electrolytes and the cell is depolarized (see Fig. 1). This depolarization causes the cell to contract. The resting cell potential is then quickly restored by the reshuffling of electrolytes in the process called repolarization.[7]

In the heart the depolarization begins in the sinoatrial (SA) node which lies in the wall of the left atrium (see Fig. 2). The SA node is a specialized tissue known as the pacemaker. The impulse spreads through the muscle fibers of the atria resulting in atrial contraction. From the muscle fibers the impulse travels to the atrioventricular (AV) node, which is located in the lower portion of the right atrium. The impulse is delayed slightly in the AV node to allow sufficient time for the atria to contract. The impulse is next propagated along the atrioventricular (AV) bundle, also called the Bundle of His. The AV bundle divides into the right and left bundle branches which subdivide into the Purkinje fibers. The impulse spreads from the Purkinje fibers through the

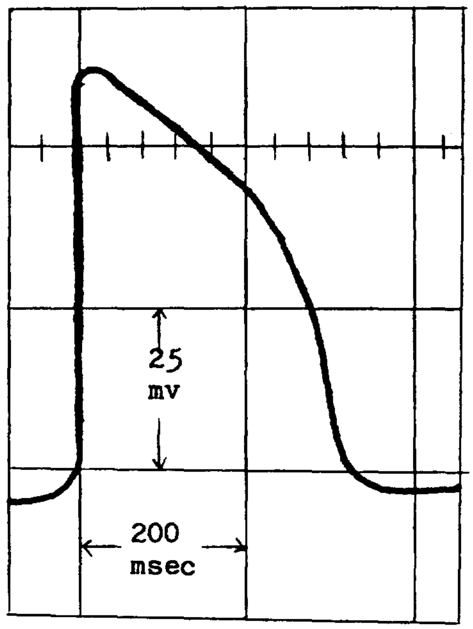


Fig. 1. Intracellular recording of the action potential from the ventricle of a frog. This figure was taken from Ref. 7.

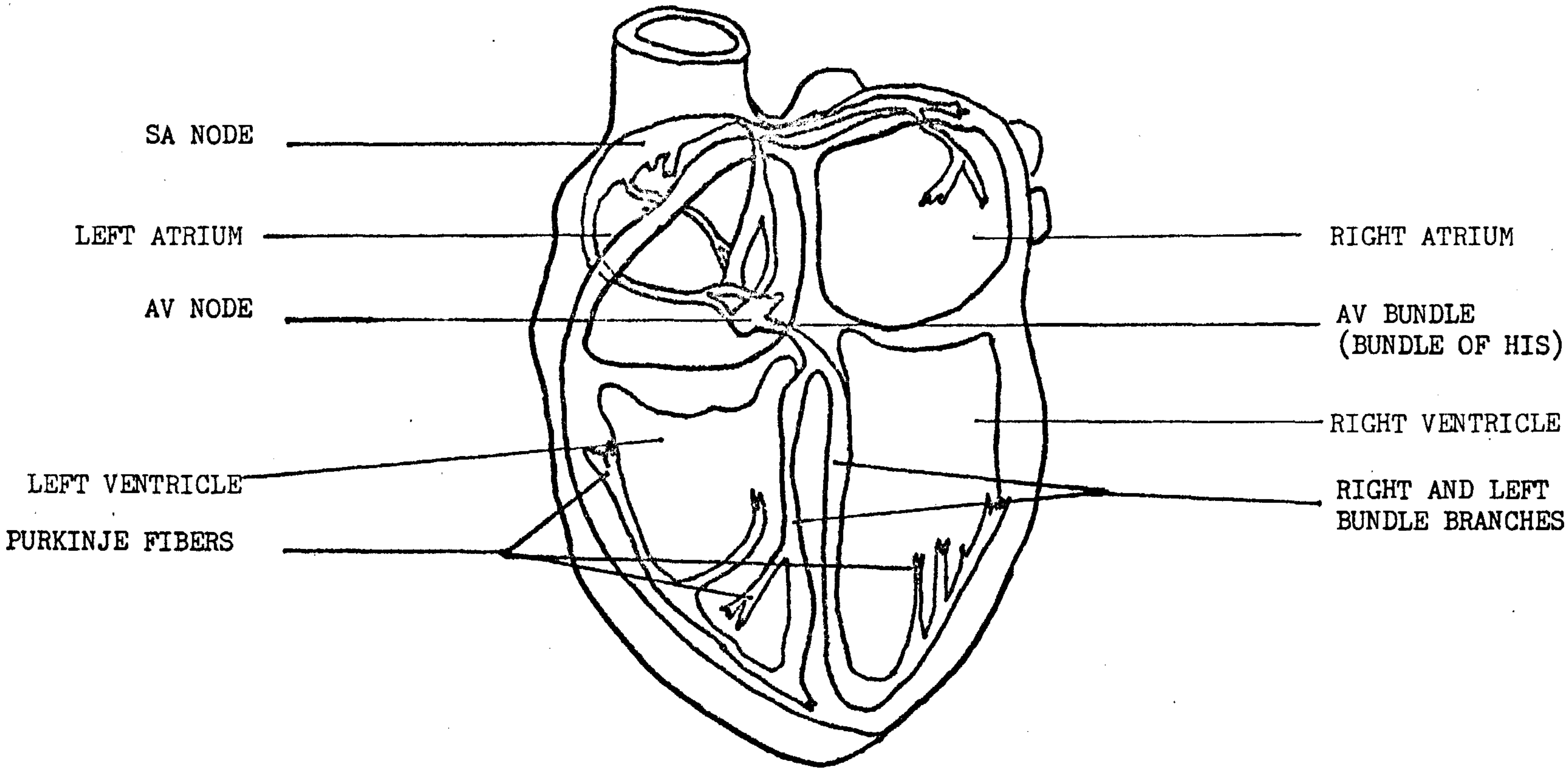


Fig. 2. Electrical conduction system of the heart. This figure was taken from Ref. 8.

ventricular muscles, causing ventricular contraction.[8]

B. The Characteristics of an Electrocardiogram

The propagation of the electrical impulse of the heart can be monitored from the exterior surface of the body. The first measurable impulse is the depolarization of the atria. This is known as the P wave (see Fig. 3). The flat segment following the P wave represents the delay that occurs in the AV node. The QRS complex is the most prominent portion of the trace; it results from the depolarization of the ventricles. The T wave signals the repolarization of the ventricles. The short segment between the QRS and T waves is known as the ST segment. The last wave that occasionally appears is called the U wave. It appears during the time when the ventricles are relaxed. Its significance is complex[8] and is often not included in discussions of electrograms.

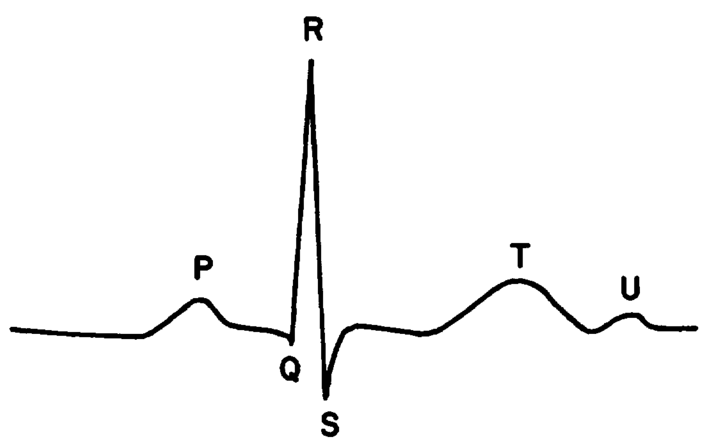


Fig. 3. Waves of the cardiac cycle. This figure was taken from Ref. 8.

III. FOURIER ANALYSIS

Since the electrocardiogram is a periodical, repeating function, it can be expresses as a linear combination of sine and cosine functions.

The Fourier series for the function f(t) is given by:[4]

$$f(t) = \tfrac{1}{2}A_o + \sum_{n=1}^{\infty} (A_n \cos(2\pi n f_o t) + B_n \sin(2\pi n f_o t))$$

where f_o is the frequency, given by $1/T_o$ when T_o is the period of the wave. A_n and B_n are the amplitudes of the cosine and sine waves, respectively. They are determined by the equations:

$$A_n = (2/T_o) \int_{-\frac{1}{2}T_o}^{\frac{1}{2}T_o} f(t)\cos(2\pi n f_o t)dt \qquad n=0,1,2...$$

and

$$B_n = (2/T_o) \int_{-\frac{1}{2}T_o}^{\frac{1}{2}T_o} f(t)\sin(2\pi n f_o t)dt \qquad n=1,2,3...$$

The power spectrum is obtained by plotting C_n as a function of frequency where C_n is called the power spectrum coefficient and is given by the relation

$$C_n = \tfrac{1}{2}(A_n{}^2 + B_n{}^2).$$

In this investigation, a Fast Fourier Transform computer program, developed by Larry McCutchan at Ball State University, was used to compute the Fourier power spectra. The interested reader may refer to Ref. 4 for additional information concerning the program and Fourier analysis. A typical EKG trace and resulting Fourier power spectrum are given in Fig. 4.

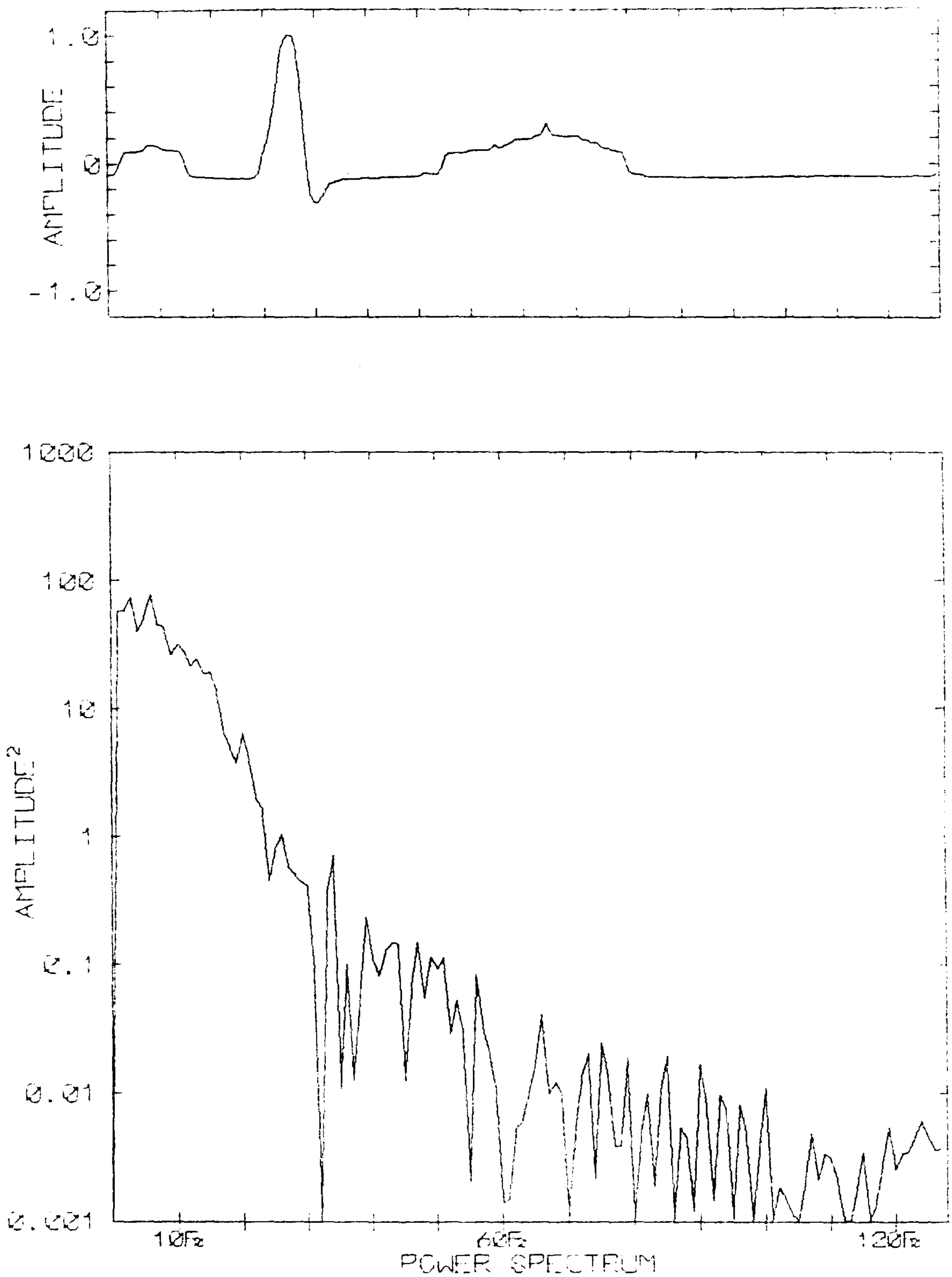


Fig. 4. Typical EKG trace and Fourier power spectrum.

IV. EXPERIMENTAL PROCEDURE

A. Experimental Apparatus

The system used for this study was originally developed by Larry McCutchan in a previous study at Ball State University.[4]

The differential input EKG amplifier was designed by P. R. Errington at BSU. It amplified the millivolt skin surface potential by a factor of about 3600. The sixty hertz notch filter was used to eliminate sixty cycle noise. The voltage to-frequency converter used a model 8038 function generator to convert the EKG voltage to an output frequency which is proportional to the EKG potential. A Nuclear Data 2200 multichannel analyzer (MCA) was used to record the output frequency of the circuit as a function of time, hence obtaining a digitized trace which was sent directly to the DEC-10 BSU computer. The modification that allowed direct transfer of the digitized data from the MCA to the computer was made during the course of this investigation. Shown in Fig. 5 is a block diagram of the modified apparatus.

Before the modification in the data acquisition system, the digitized data read from the MCA was punched onto paper tape at 110 baud (characters per minute). This was then read via a Model 33 Teletype to the DEC-10 computer, again at 110 baud. The system modification included changing a capacitor, resistor combination in the MCA and inserting an opto-isolator IC 4N28 between the computer receive lines and the MCA send lines. This allowed direct transfer of data at 2400 baud. Thus the transfer time was reduced from about thirty minutes to forty seconds when analyzing one day's

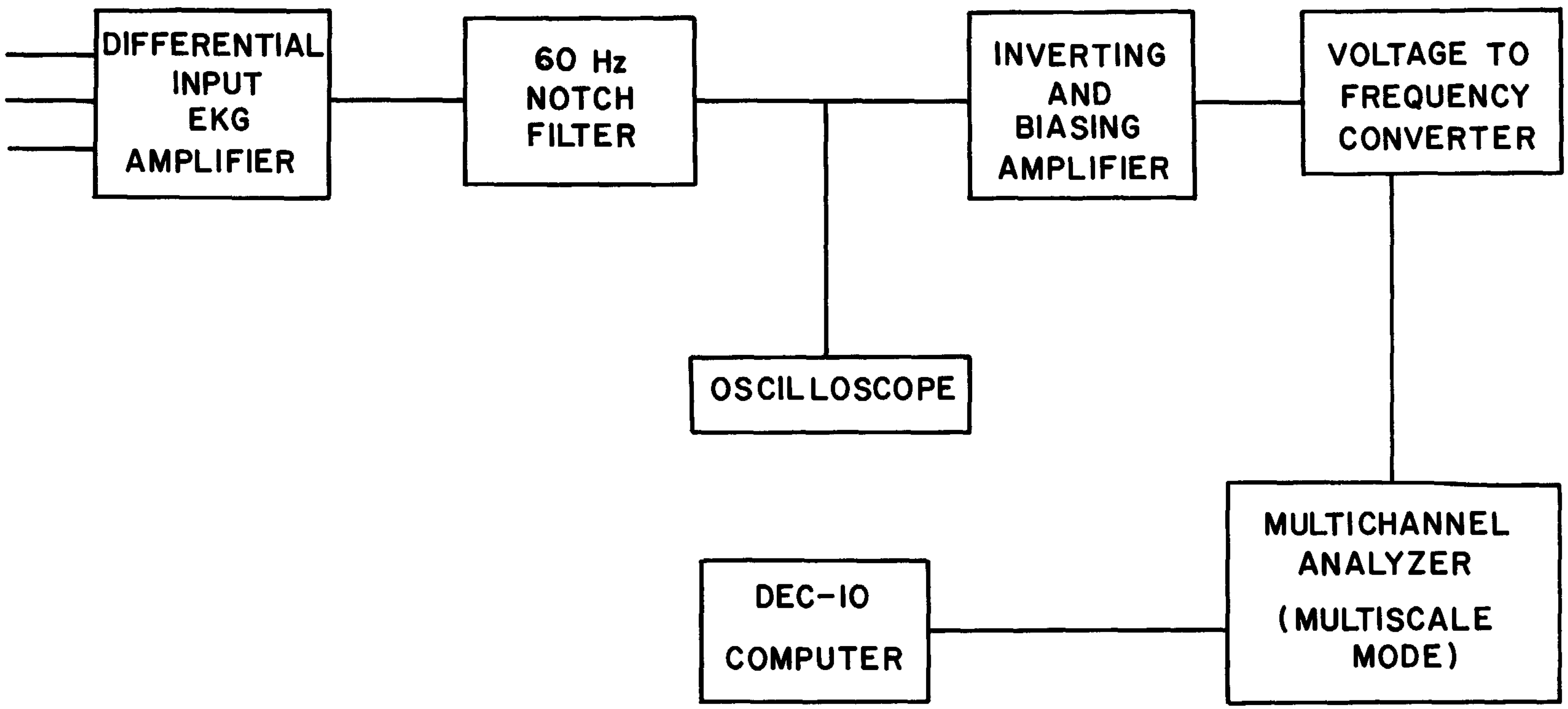


Fig. 5. Block diagram of experimental apparatus. The oscilloscope was used only for monitoring.

data--four seconds of EKG data, digitized into 1024 words. A block diagram illustrating the modification and time reduction is shown in Fig. 6.

B. Experimental Subject

The statistical variations in the Fourier power spectrum of the EKG for one female subject (this investigator) were studied over a period of eleven months from January to November 1977. During this time the subject enrolled in PGW 104 (Jogging) at Ball State University. This course was designed to increase the student's cardiovascular fitness with jogging.

At the beginning of the program, the subject intermittently walked and jogged a total distance of about one and a half miles in approximately sixteen minutes. Continuation of this procedure built up the subject's endurance so that at the end of the program, she could jog continuously for three miles at a nine minute per mile pace.

C. Experimental Data

Data that was analyzed in this investigation consisted of three separate sets with each set containing one hundred cycles of electrocardiograms. The first set was taken in January and February of 1977 before the conditioning program was initiated. During this time and for twenty-five days, four seconds of EKG data were digitized (256 points per second) and recorded, yielding at least four complete cycles of EKG trace per day and a total of one hundred EKGs. A second set of measurements was taken during the period that the

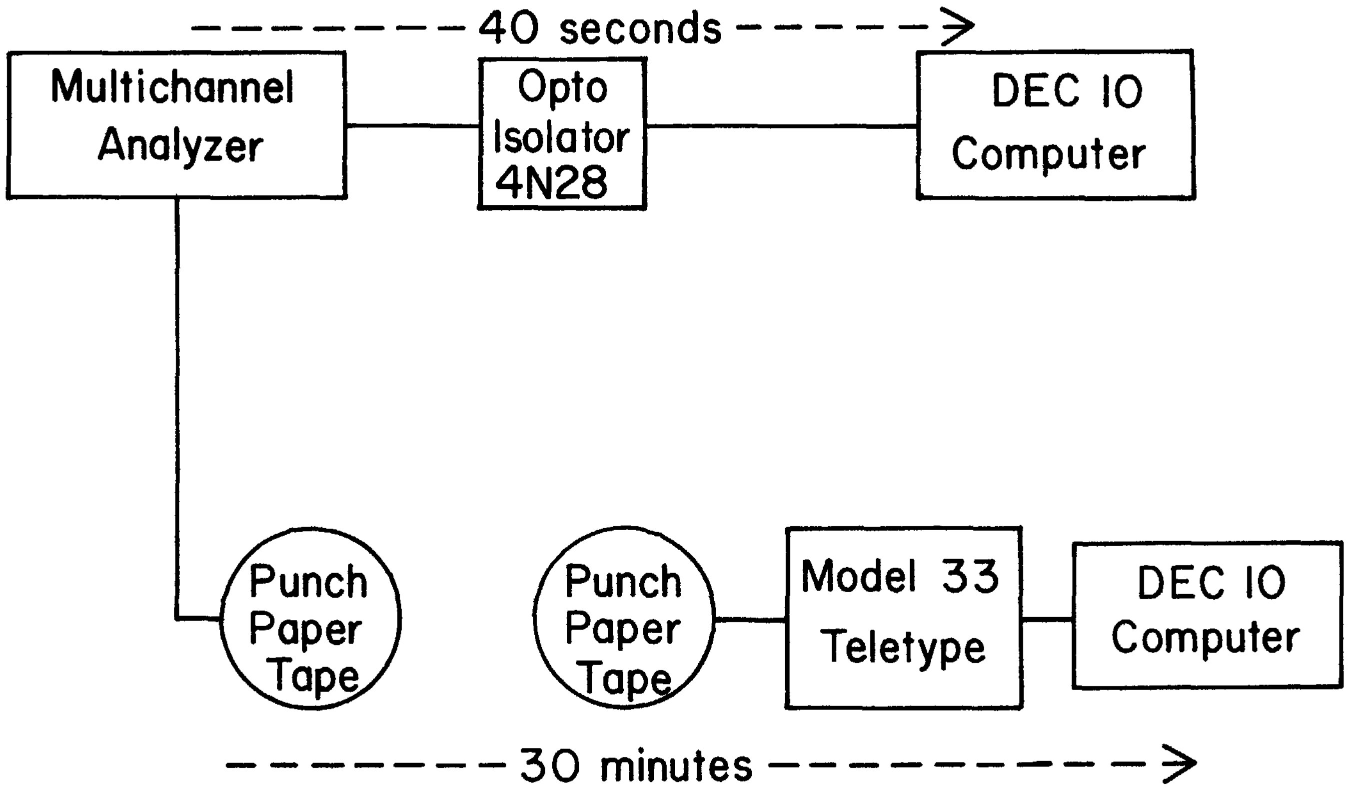


Fig. 6. Block diagram comparing the data transfer process before and and after the system modifications. The lower scheme represents the transfer process before the modifications.

subject was undergoing the exercise program. This took place in September through November 1977. Again during twenty-five days, EKG data was recorded in the manner previously described. The final set of data was recorded after the subject had completed the conditioning program in late November 1977. This set also consisted of twenty-five separate recordings, each with four seconds of data. These twenty-five recordings were obtained in one day under the assumption that the Fourier power spectra from a given day will fluctuate about an average power spectrum in the same way as Fourier power spectra from a period of days.

D. Experimental Lead Configuration

The position of the electrodes on the body is important in determining the appearance of the EKG trace. In this study, the Lead I configuration was used. In this configuration, electrodes are attached to the right (RA) and left (LA) arms. The right ankle serves as an electrical ground. Because of the position of the heart, the RA electrode is closer to the base of the heart than the LA electrode. When the depolarization of the muscle begins, the RA electrode becomes electronegative with respect to the LA electrode. By convention, the electrodes are connected to the EKG recorder in a manner that causes an upward deflection when the RA electrode becomes negative.[7]

V. ANALYSIS OF DATA

A. T-test

When making statistical comparisons, one is often interested in knowing whether or not there is a significant difference between the means of the two data groups. One test to determine this is known as the t-test. The t value is given by the relation[9]

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{s_1^2/n_1 + s_2^2/n_2}$$

where μ_1 and μ_2 are the mean values of groups one and two, respectively; $\bar{x}_1$ and $\bar{x}_2$ are the means of the sample chosen from group one and group two, respectively; and s^2 for a sample is an estimate of the variance given by

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$$

where n equals the number of elements in the sample. As can be seen by the definition of t, physically a large t value indicates a statistical difference does exist between the two groups of data; hence, there is low probability that $\mu_1 = \mu_2$.

The computer program used in this investigation to perform the t-test is found in the Statistical Package for the Social Sciences which is available on the DEC-10 Ball State University computer.[9]

B. Averaging the Data

The three sets of data were prepared for comparison by two methods. First, the average power spectrum for each set of one hundred EKGs was calculated. Secondly, the four EKG Fourier power spectra from each day's EKG data were averaged to yield an average daily power spectrum. Thus, twenty-five average daily power spectra resulted. This procedure allowed one to study the daily changes that were taking place during the conditioning program.

VI. RESULTS

Throughout the remainder of the paper, set one will refer to the data taken before the conditioning program, set two to the data taken during the conditioning period, and set three to the data obtained after the conditioning program was completed.

Only the first thirty-one coefficients will be noted because it has been found that for the higher harmonics, the standard deviation was greater than the magnitude of the average power spectrum coefficient. In all cases, C_o was equal to zero due to the arbitrary scaling factor of the EKG trace.

A. Comparisons of EKG Power Spectrum Before and After Conditioning

T-tests were performed to determine which coefficients if any had changed during the physical conditioning program. T-tests were done on both set one and three data of the twenty-five average daily power spectra and the one hundred Fourier power spectra.

All of the coefficients from one to thirty-one showed significant change except those corresponding to n=4,5,10,12,27,29, and 30. All others showed less than a probability of 0.05 that $\mu_1 = \mu_2$. The coefficients which had a probability of 0.000 that $\mu_1 = \mu_2$ corresponded to n=1,2,3,7,8,9,14,15,16,17,18, and 23. The t-values and the probability of correlation between data sets one and three are given in Table 1.

The change in the average Fourier power spectrum between sets

Table 1. T values and probabilities of correlation for the comparisons of the first thirty coefficients of the three sets of data.

	SETS ONE-THREE		SETS ONE-TWO		SETS TWO-THREE	
N	T-VALUE	PROBABILITY OF CORRELATION	T-VALUE	PROBABILITY OF CORRELATION	T-VALUE	PROBABILITY OF CORRELATION
0	0.000	1.000	0.000	1.000	0.000	1.000
1	-3.930	0.000	-6.140	0.000	3.030	0.003
2	-4.530	0.000	1.150	0.250	-6.050	0.000
3	-5.530	0.000	-2.500	0.013	-3.270	0.001
4	-0.190	0.846	-4.150	0.000	3.770	0.000
5	-0.810	0.416	5.650	0.000	-6.310	0.000
6	-2.870	0.005	2.990	0.003	-6.470	0.000
7	7.640	0.000	-0.180	0.855	7.350	0.000
8	8.040	0.000	7.440	0.000	0.940	0.347
9	4.100	0.000	5.100	0.000	-1.160	0.246
10	2.370	0.019	4.730	0.000	-2.880	0.004
11	-0.030	0.978	4.850	0.000	-6.000	0.000
12	1.020	0.310	2.050	0.042	-1.160	0.248
13	6.030	0.000	2.800	0.006	3.480	0.001
14	5.970	0.000	0.960	0.339	5.300	0.000
15	4.210	0.000	-1.720	0.087	5.620	0.000
16	4.690	0.000	-2.980	0.003	7.450	0.000
17	5.010	0.000	-2.810	0.005	8.250	0.000
18	4.940	0.000	-2.150	0.033	7.360	0.000
19	3.270	0.001	-3.640	0.000	6.670	0.000
20	3.350	0.001	-3.900	0.000	7.230	0.000
21	3.270	0.001	-3.980	0.000	7.050	0.000
22	3.310	0.001	-3.330	0.001	6.570	0.000
23	4.280	0.000	-2.840	0.005	7.250	0.000
24	2.560	0.011	-3.300	0.001	5.850	0.000
25	2.110	0.036	-3.100	0.002	5.380	0.000
26	2.960	0.003	-3.780	0.000	6.360	0.000
27	1.660	0.098	-2.780	0.006	4.460	0.000
28	1.980	0.049	-2.660	0.009	4.380	0.000
29	1.970	0.050	-1.850	0.066	3.720	0.000
30	0.650	0.516	-2.930	0.004	3.520	0.001

one and three can be noted in Fig. 7. The first thirty-one coefficients are tabulated in Table 2 where the percent of change between the two sets have been calculated. Coefficients n=1,2,18,20,21,22, 23,24, and 26 changed by over twenty percent. Coefficients n=4 and 11 had less than a one percent change.

B. Conditioning Period EKG Power Spectrum in Comparison with the Other Spectra

Set two represents the transitional period between sets one and three during which time training took place. Of particular interest are gradual trends in the coefficients as the conditioning progressed. Treating the sets as three separate time series (see Appendix A) and plotting each coefficient as a function of day, a least squares fit to a straight line was done to determine trends in the data. Slopes and their uncertainties for the first thirty-one coefficients for each set of data are listed in Table 3.

In determining the trend of the coefficients, one must examine the slope of the coefficients during the transitional period as compared to that during a nontransitional period. The slope of the coefficients as a function of day from the set one and set two data were compared since both sets were recorded over a period of many days. The slopes that changed in sign from set one to set two were the slopes associated with coefficients n=1,3, 4,5,9,11,12,21,29, and 30. For only the coefficients n=2,6,7,16, 18, and 28 did the slope change by less than one hundred percent, with coefficient n=18 showing no change at all. Also it is interesting to note that the uncertainty to slope ratio decreased from

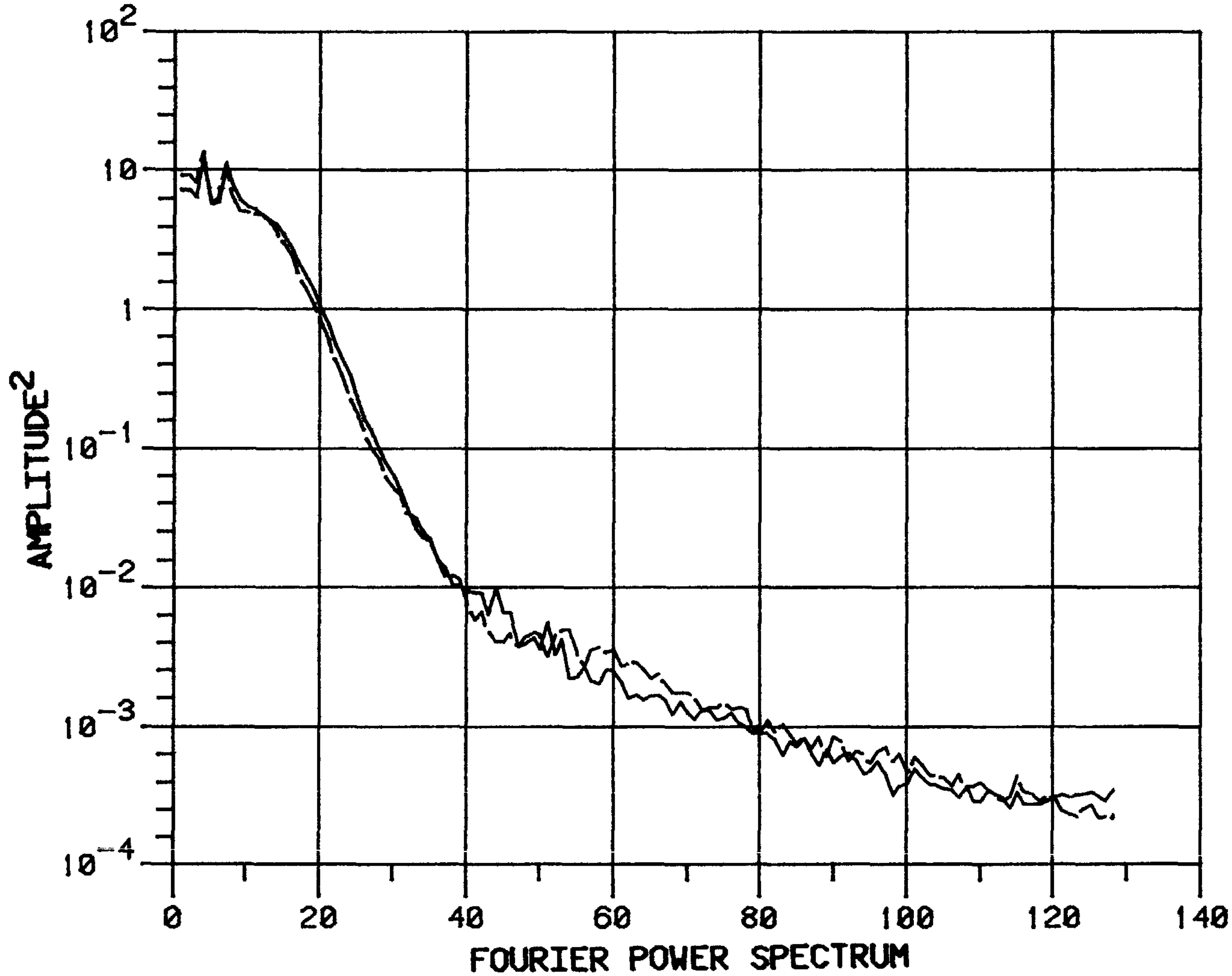


Fig. 7. Comparison of the average Fourier power spectra from sets one and three. The solid line represents the set one spectrum, and the broken line the set three spectrum.

Table 2. The first thirty-one average Fourier power spectrum coefficients for the three sets of data and the percent change between sets one and three.

	Coefficient Amplitude			
n	Set one	Set two	Set three	Percent change set one to three
0	0.0000000	0.0000000	0.0000000	00.0
1	7.0390345	10.5167565	9.1026383	29.3
2	6.2585428	5.8345688	7.9396758	26.7
3	11.9626944	12.6702541	13.4321290	12.3
4	5.6450359	6.7995415	5.6967175	0.9
5	5.8982097	3.3298080	6.3420423	7.5
6	10.3886180	9.2250814	11.2820324	8.6
7	7.7152201	7.7495651	6.2270519	-19.3
8	5.9641388	5.0253380	4.9027495	-17.8
9	5.3393421	4.7985200	4.9003496	- 8.1
10	5.0685354	4.4843071	4.7785215	- 5.7
11	4.7822261	4.2130854	4.7851430	0.1
12	4.3175148	4.1177715	4.2244896	- 2.2
13	4.0161500	3.7934841	3.5262226	-12.2
14	3.4504600	3.3801886	2.9806065	-13.6
15	2.7310828	2.8670152	2.3344866	-14.5
16	2.1395077	2.3882114	1.7193955	-19.6
17	1.7290266	1.9337032	1.3847162	-19.9
18	1.3719903	1.5070167	1.0715674	-21.9
19	1.0111792	1.2215666	0.8297476	-17.9
20	0.7606863	0.9608806	0.6051231	-20.5
21	0.5608765	0.7291230	0.4309739	-23.2
22	0.4260645	0.5538313	0.3224889	-24.3
23	0.3294843	0.4162228	0.2273795	-31.0
24	0.2188270	0.2954956	0.1727664	-21.0
25	0.1643024	0.2230082	0.1333533	-18.8
26	0.1287155	0.1872667	0.0967197	-24.9
27	0.0972315	0.1317577	0.0821230	-15.5
28	0.0775306	0.1032174	0.0635733	-18.0
29	0.0611187	0.0751458	0.0489985	-19.8
30	0.0475694	0.0666779	0.0441855	- 7.1

Table 3. The slopes and their uncertainties of the first thirty-one Fourier power spectrum coefficients as a function of time, and the percent change between sets one and two.

n	Set one	Set two	Set three	Percent change set one to two
1	0.0949±0.1052	-0.1248±0.0832	0.2741±0.0438	-231.5
2	-0.0749±0.0526	-0.0666±0.0516	-0.0481±0.0426	11.1
3	0.0278±0.0485	-0.0883±0.0323	-0.0854±0.0290	-417.6
4	0.0040±0.0392	-0.0297±0.0470	0.0438±0.0363	-842.5
5	-0.0569±0.0915	0.0699±0.0617	-0.1198±0.0764	222.8
6	-0.0911±0.0629	-0.0222±0.0617	0.0050±0.0249	75.6
7	0.0365±0.0259	0.0242±0.0304	-0.0223±0.0297	- 33.7
8	0.0122±0.0158	0.0363±0.0162	-0.0787±0.0138	197.5
9	0.0081±0.0187	-0.0030±0.0132	-0.0271±0.0124	-137.0
10	0.0033±0.0226	0.0229±0.0163	-0.0006±0.0149	593.9
11	-0.0065±0.0208	0.0219±0.0168	-0.0113±0.0099	436.9
12	-0.0019±0.0140	0.0164±0.0160	-0.0214±0.0112	763.2
13	0.0023±0.0107	0.0203±0.0113	-0.0085±0.0096	782.6
14	0.0059±0.0079	0.0191±0.0104	0.0050±0.0097	223.7
15	0.0006±0.0091	0.0060±0.0122	0.0172±0.0131	900.0
16	0.0072±0.0116	0.0139±0.0124	0.0153±0.0117	93.1
17	0.0069±0.0114	0.0145±0.0092	0.0054±0.0060	110.1
18	0.0081±0.0093	0.0081±0.0086	0.0045±0.0066	0.0
19	0.0045±0.0080	0.0094±0.0096	0.0066±0.0067	-108.9
20	0.0000±0.0070	0.0100±0.0079	0.0086±0.0057	****
21	-0.0027±0.0056	0.0077±0.0060	0.0078±0.0042	385.2
22	0.0029±0.0053	0.0081±0.0056	0.0037±0.0030	179.3
23	0.0005±0.0045	0.0033±0.0041	0.0022±0.0020	560.0
24	0.0015±0.0032	0.0040±0.0037	0.0022±0.0015	166.7
25	0.0007±0.0028	0.0038±0.0029	0.0039±0.0010	442.9
26	0.0007±0.0019	0.0031±0.0024	0.0022±0.0009	342.8
27	0.0005±0.0016	0.0025±0.0018	0.0011±0.0006	400.0
28	0.0009±0.0011	0.0015±0.0013	0.0012±0.0007	66.7
29	-0.0005±0.0009	0.0012±0.0011	0.0015±0.0005	340.0
30	-0.0002±0.0008	0.0019±0.0010	0.0011±0.0004	1050.0

set one to set two in all cases except n=1,6, and 7. These are also the only three cases that showed a decrease in the magnitude of the slope with no change of sign.

The graphs of the coefficients vs. days for selected harmonics are presented in Appendix B.

T-tests were performed on set one and two data and also set two and three data. The results are tabulated in Table 1. Upon comparison of the t-values from these two t-tests, one can see that the magnitudes of the t-values for sets two and three are greater than the magnitudes of the t-values for sets one and two in all coefficients except those associated with n=1,4,8,9, and 12. This shows that during the conditioning period, the coefficients were closer in value to the set one data than the set three data with the exception of the five coefficients listed above.

Graphs of the t-values and the probabilities of correlation as a function of coefficient number for the three t-tests are shown in Appendix C.

C. Comparison of Changes to ST Criteria

As cited in the introduction, McCutchan[4] developed two criteria for determining ST depression in EKG Fourier power spectrum. The first concerned the power spectrum coefficient C_2. This investigation showed that the average C_2 went from 6.2585 in set one to 7.9397 in set three. This represents a change of 26.7%. The ST score developed by McCutchan changed from 0.2445 in set one to 0.1588 in set three; a change of -35.1%. Both of these indicate a change toward ST depression.

However, this is inconsistent with the trend established during the conditioning period. Set two indicates that during the conditioning period C_2 was decreasing and the ST score was increasing. The slopes of C_2 and the ST score as functions of day were -0.0666 and 0.0036, respectively. This would suggest that the conditioning stimulated a shift toward the normal criteria.

VII. CONCLUSION

The purpose of this investigation was to observe the effect of physical conditioning on the Fourier power spectrum of the EKG from one female subject. The results from this study, show that physical conditioning does change the EKG power spectrum. This is most effectively seen in the slopes of the coefficient vs. day curves for the conditioning period. The trends support an argument that physical conditioning caused a change toward the normal criteria established by McCutchan.

Another conclusion that can be drawn from this study is that the initial assumption that obtaining twenty-five recordings of EKG data in one day would yield the same results as obtaining data on twenty-five separate days was not valid. By looking at a coefficient vs. day plot (see Appendix B), one can see that twenty-five recordings from one day fluctuate about an average as do the coefficients of data taken over several days. However, the average for a given day may be quite different from that of another day. For example, in set one C_3 if twenty-five recordings were obtained on day eleven, they would average much higher than twenty-five recordings taken on day fourteen. As can be seen in the graphs, (Appendix B), the power spectrum of the data obtained on one day (set three) does not fluctuate as rapidly as those taken over several days.

The results of this study indicate that there are many areas dealing with the effect of conditioning on the EKG power spectrum that have yet to be investigated. Other subjects could be studied before, during, and after a conditioning program. Of particular interest might be the comparison of the effects of conditioning on the EKG power spectrum of a male as opposed to a female. In these investigations, the subject should be followed for a period of time before the training is begun, during the training period, and for a period of time once a high level of fitness is obtained and is being maintained. Another way that the effect of conditioning on the EKG power spectrum can be observed would be to compare the EKG power spectrum of several well-conditioned subjects with the power spectrum of several unconditioned subjects.

APPENDIX A

Time Series

A time series is defined as a set of observations taken at intervals of time.[10] Mathematically, it is a set of values $Y_1, Y_2, \ldots Y_n$ at times $t_1, t_2, \ldots t_n$.

Using time series analysis, four components or types of variations in data can be determined.

1. Long-term or secular movements refer to the general trend of the data.

2. Cyclical movements refer to the long-term oscillations about the trend line.

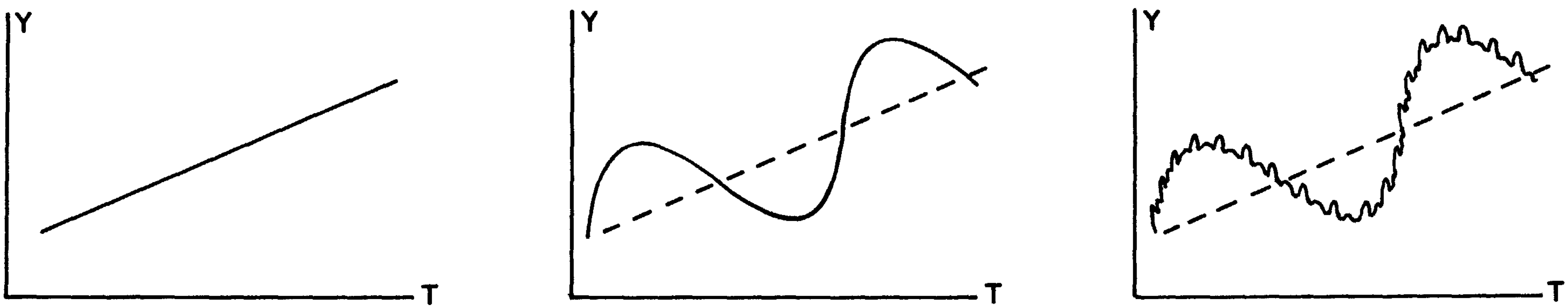
3. Seasonal movements refer to patterns which develop at certain intervals on the cyclical oscillations.

4. Irregular or random movements refer to sporadic motions in the data.

These components of the times series are illustrated in Fig. 8. When analyzing time series, it is necessary to think of the time series being made up of its four components.

The only component considered in the scope of this investigation was the long-term movements (trends). The trends were determined by finding the best straight line through the data points using a least squares fit to a straight line.

Interested readers can refer to Ref. 10 for a more complete description of time series and an explanation of the procedures for separating the components of a time series.



(a) Long-Term trend

(b) Long-Term Trend and Cyclical Movement

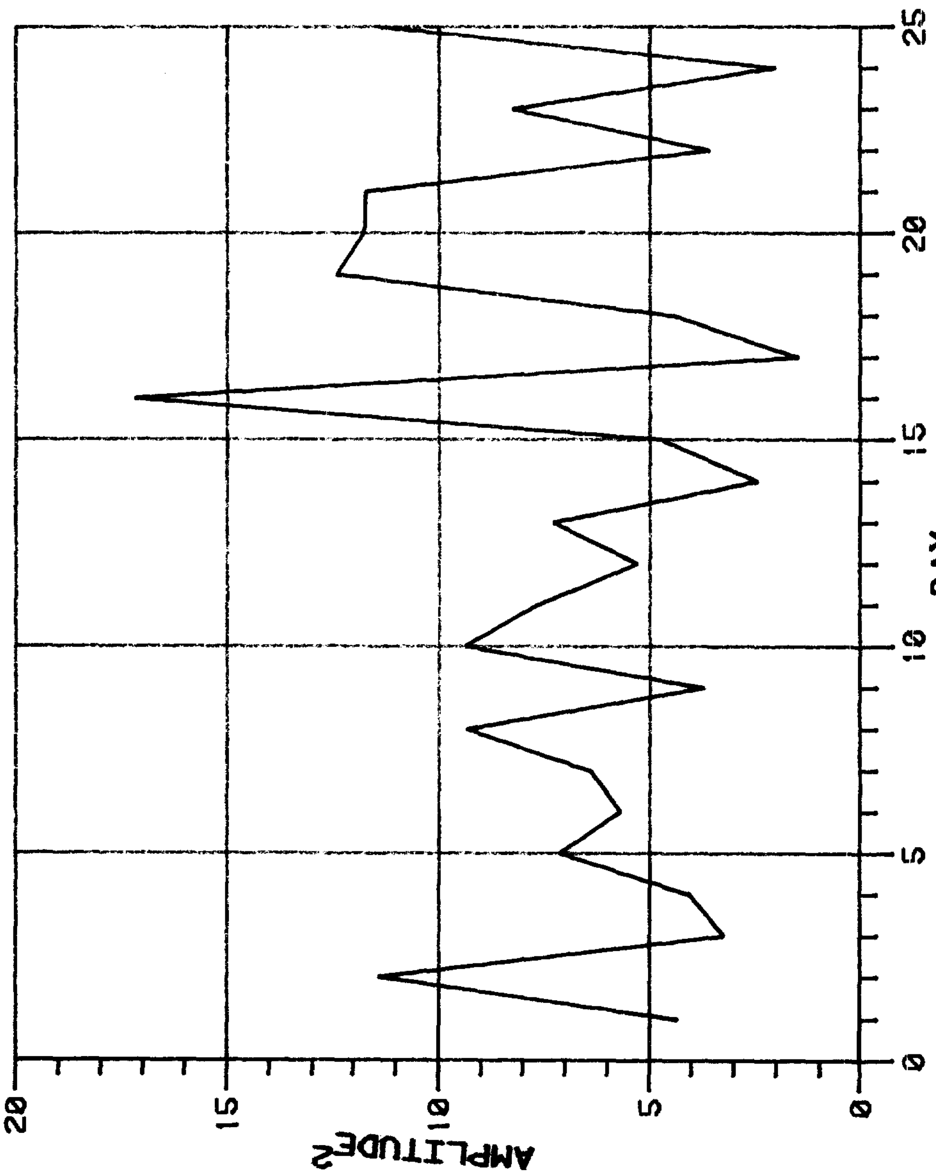
(c) Long-Term, Cyclical and Seasonal Movements

Fig. 8. Components of a time series. This figure was taken from Ref. 10.

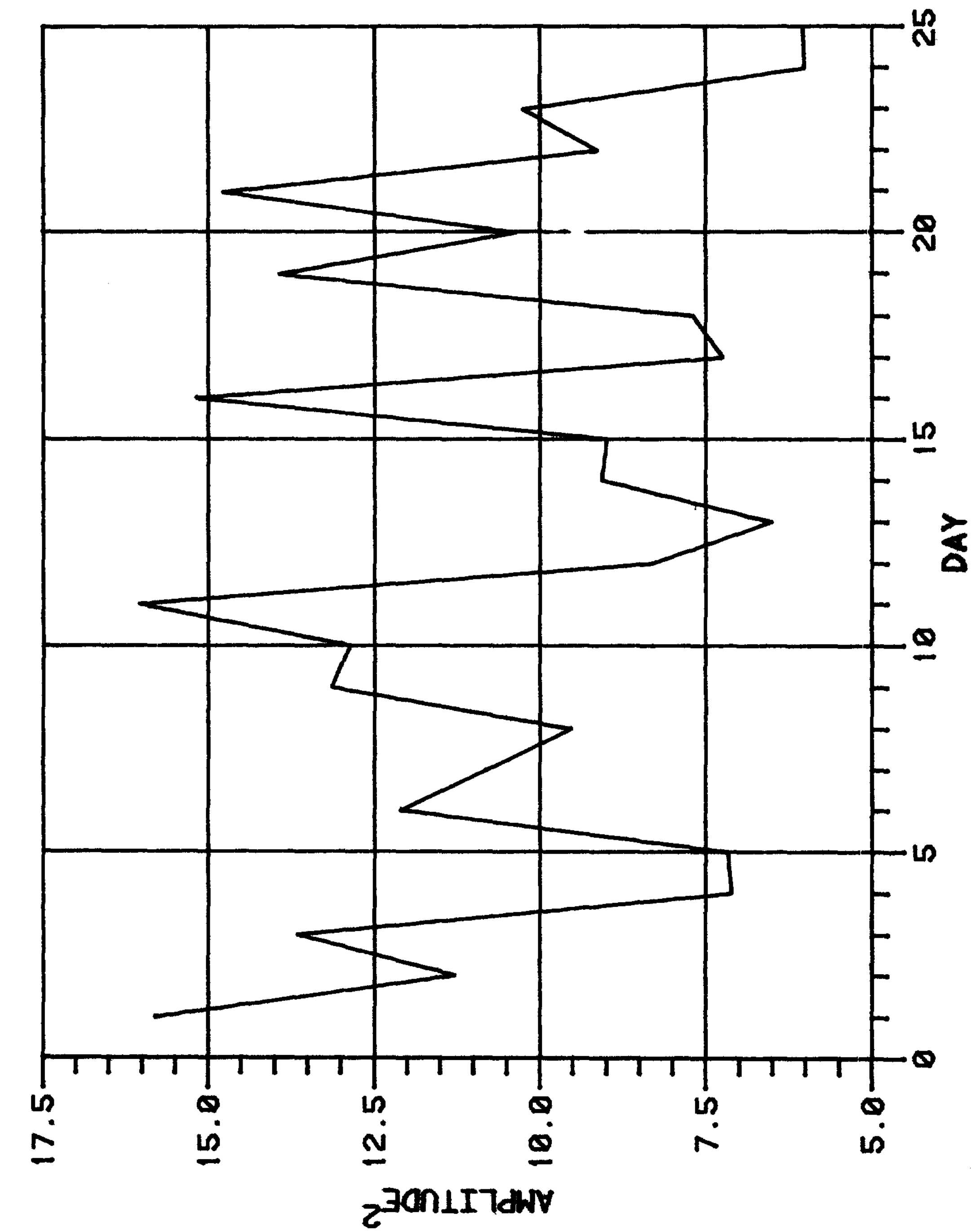
APPENDIX B

On the following pages are the plots of selected EKG Fourier power spectrum coefficients as a function of day. The graphs are arranged so that corresponding coefficients from the three sets* can be readily compared. Recall that although set three is plotted as a function of day, all twenty-five recordings were obtained in one day. Therefore, the days correspond to successive recordings.

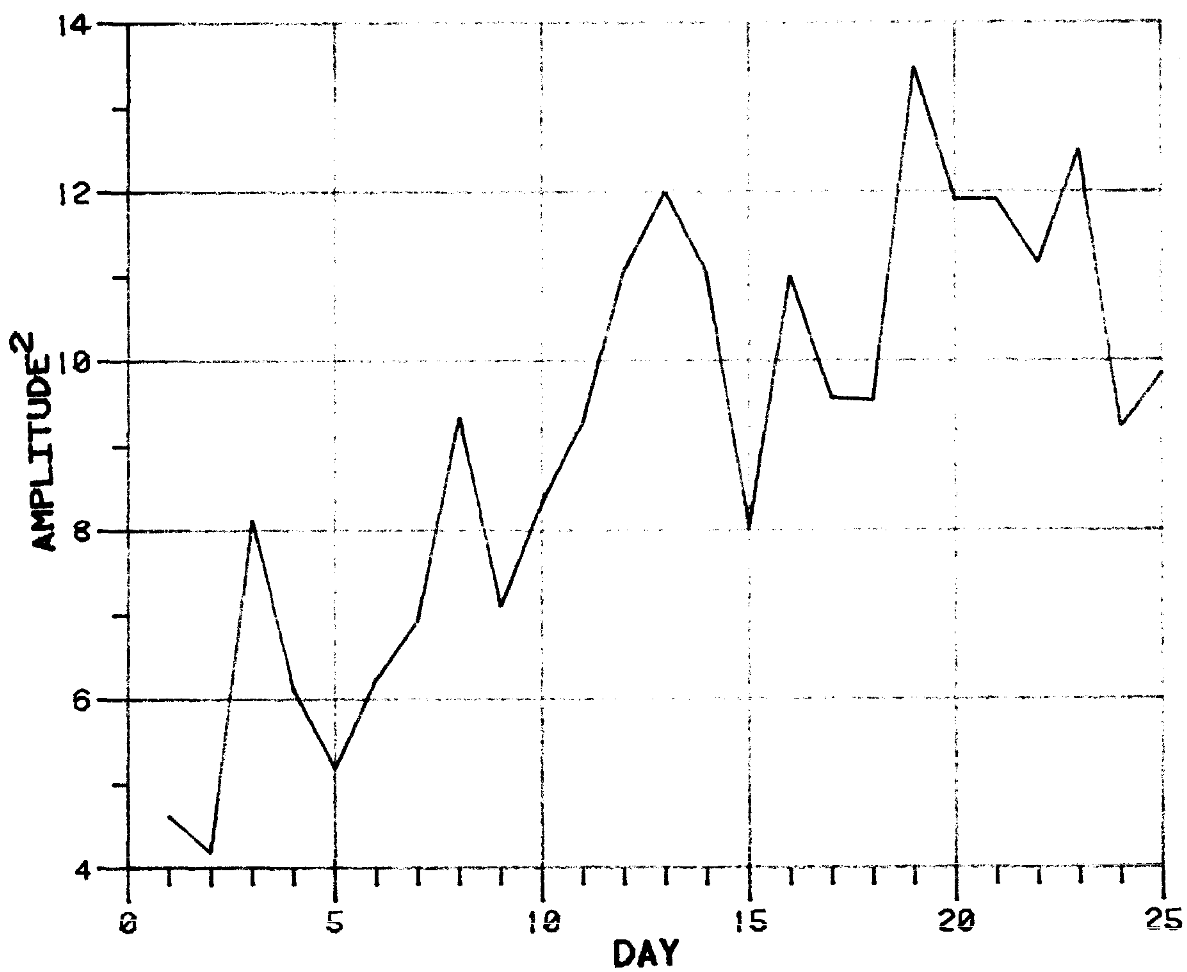
*Set one......before conditioning
Set two......during the conditioning program
Set three....after conditioning



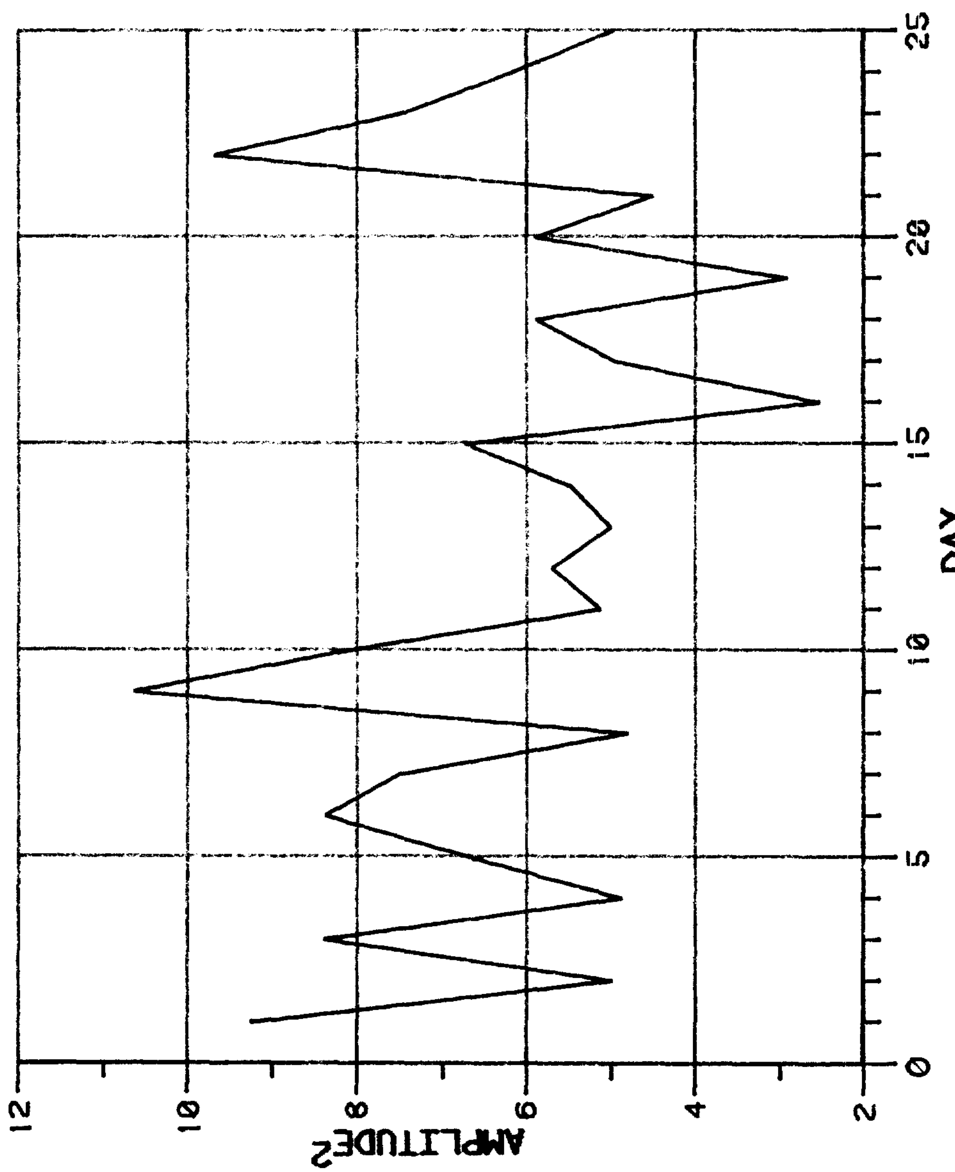
Set one C_1



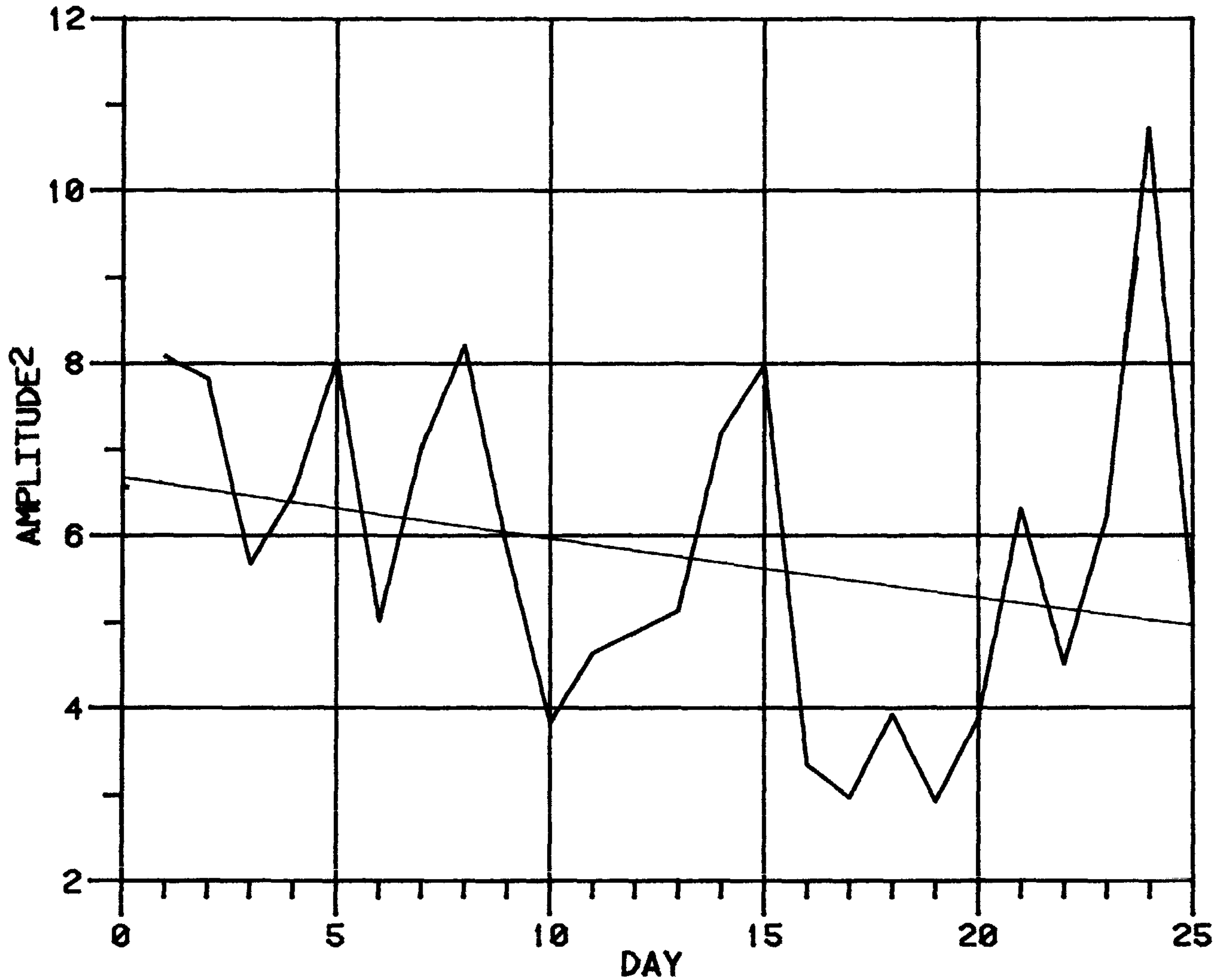
Set two C_1



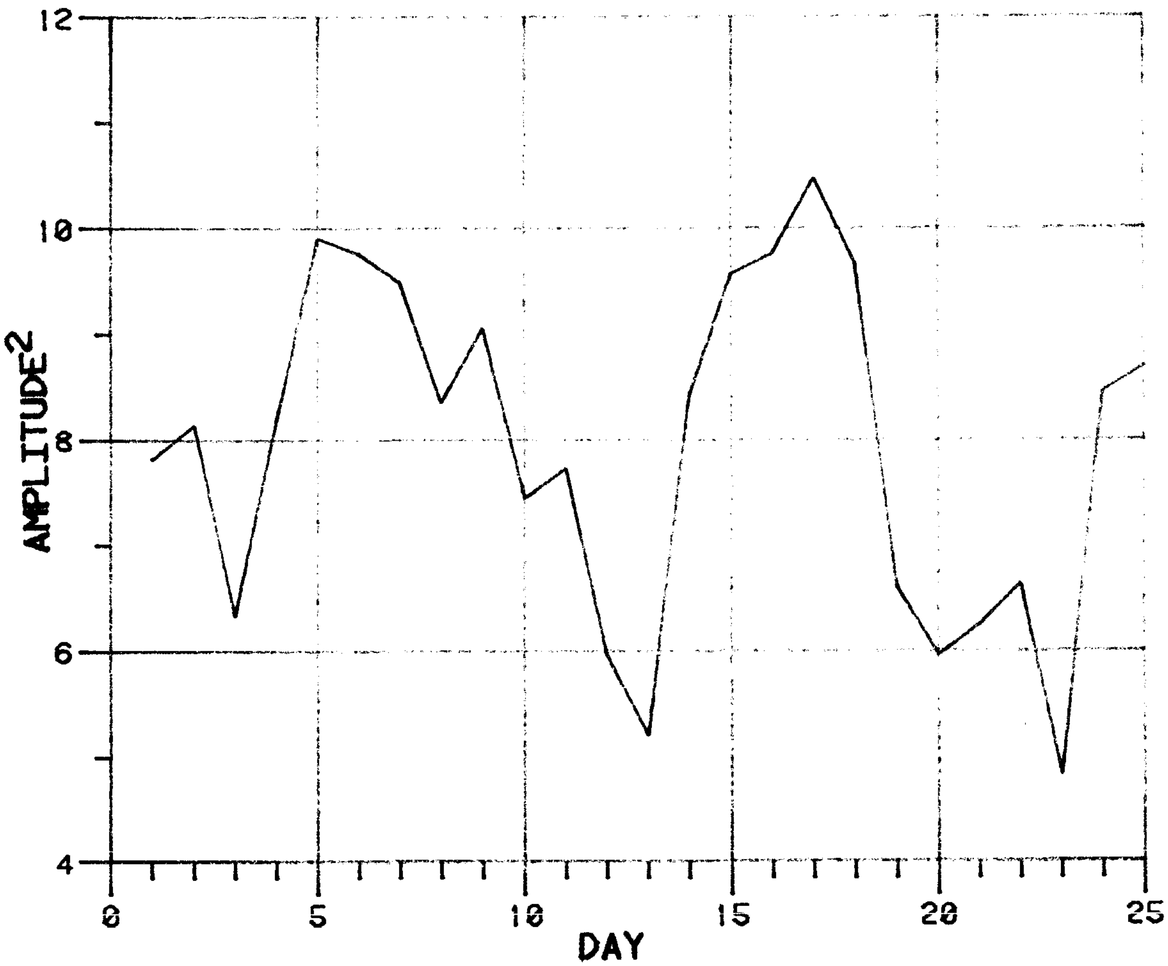
Set three C_1



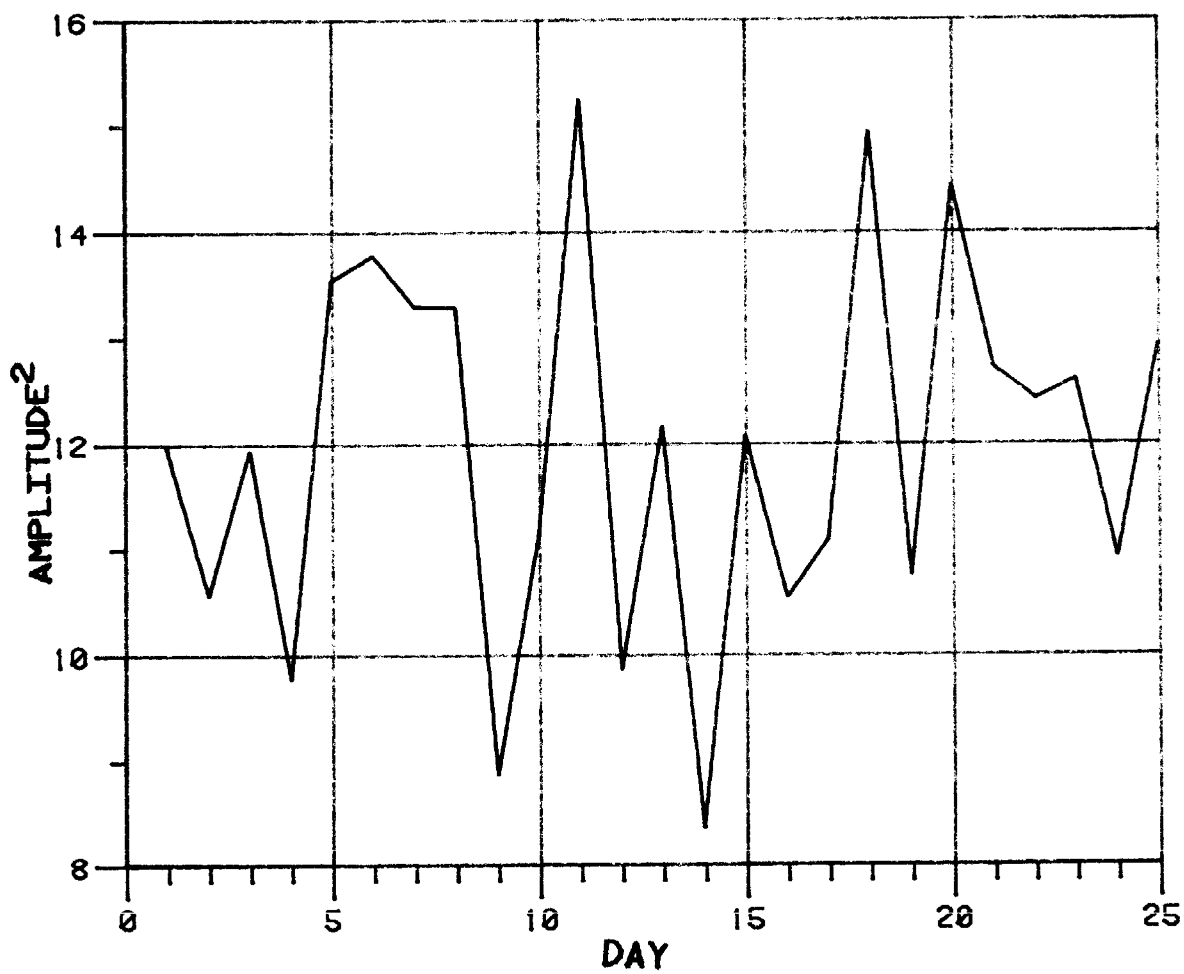
Set one C_2



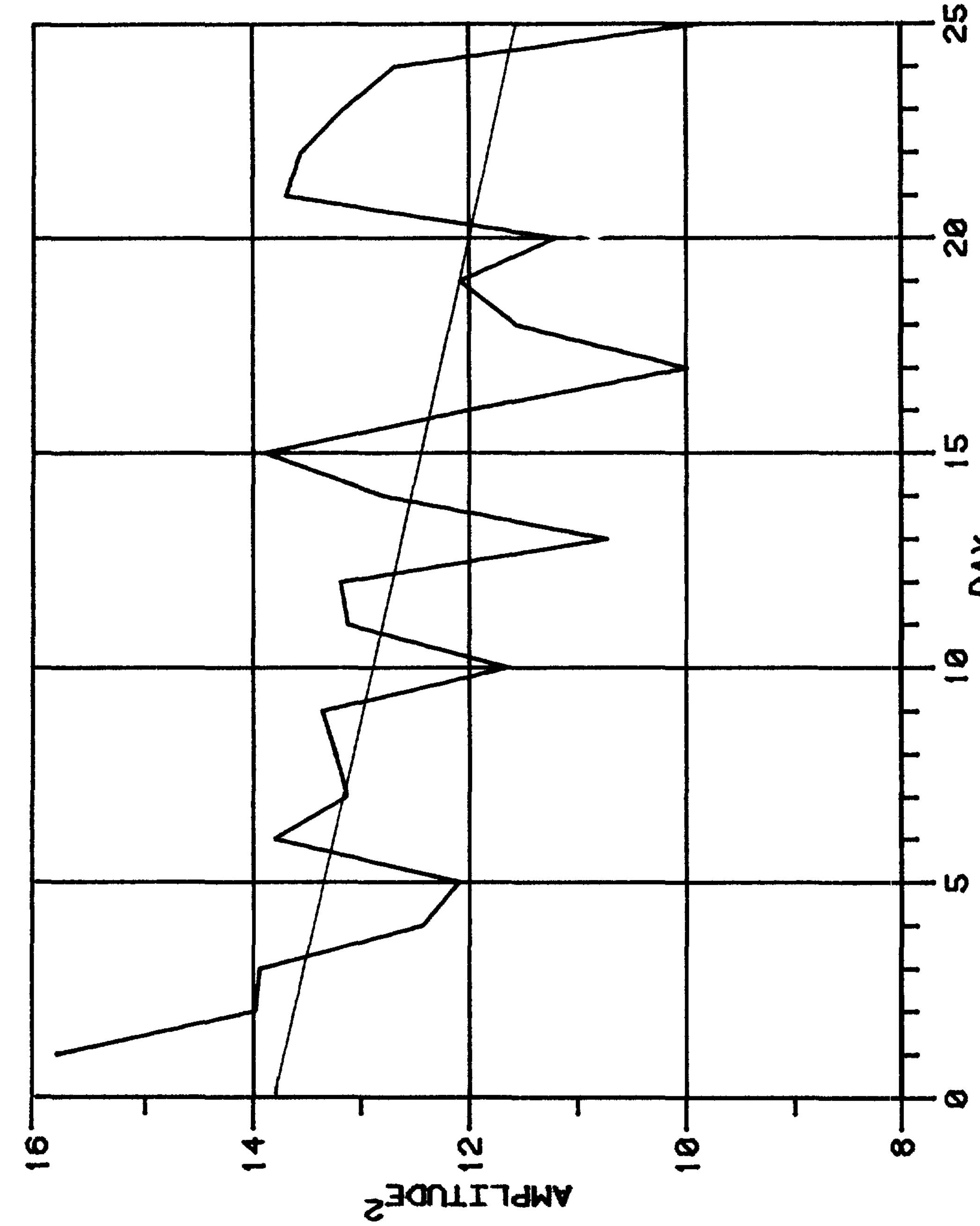
Set two C_2



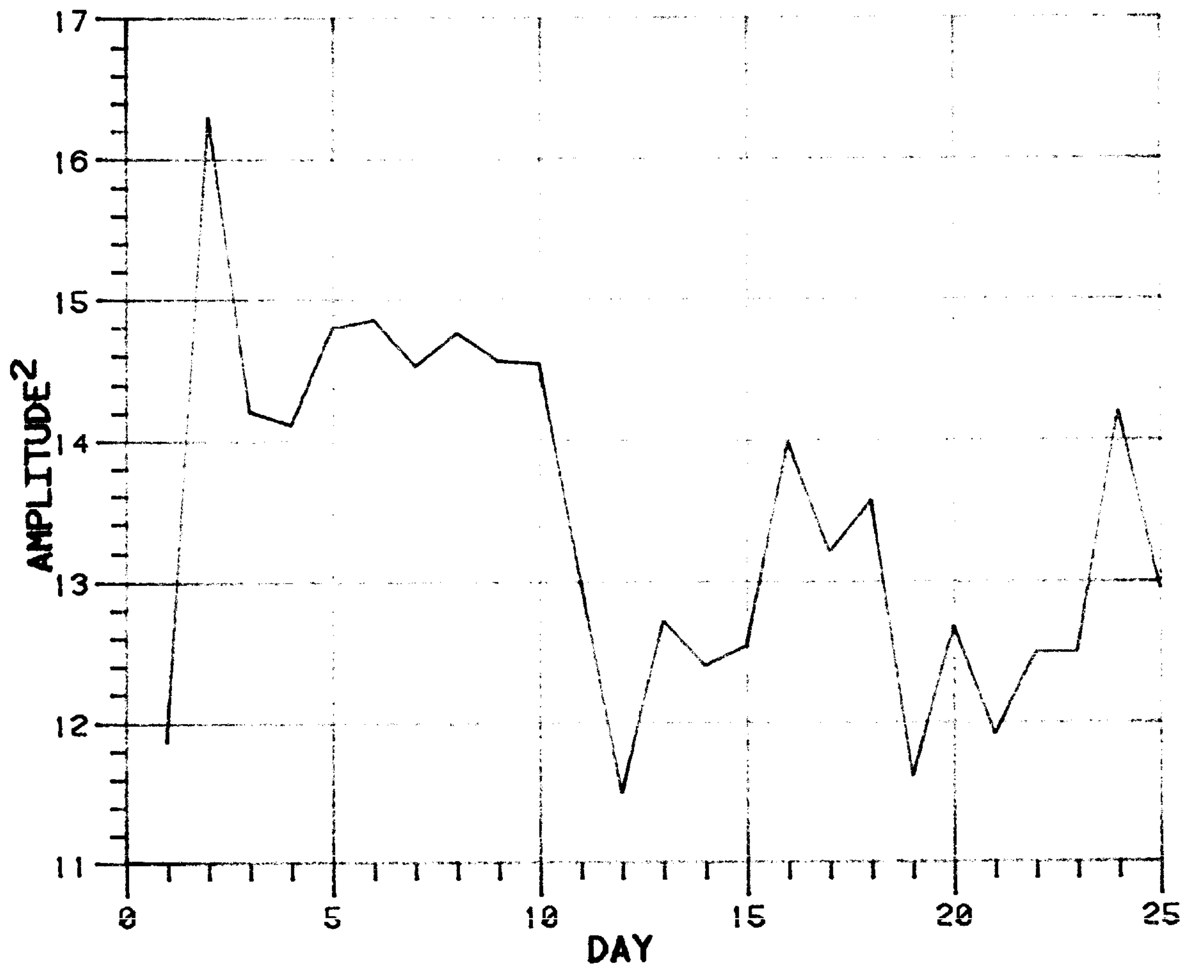
Set three C_2



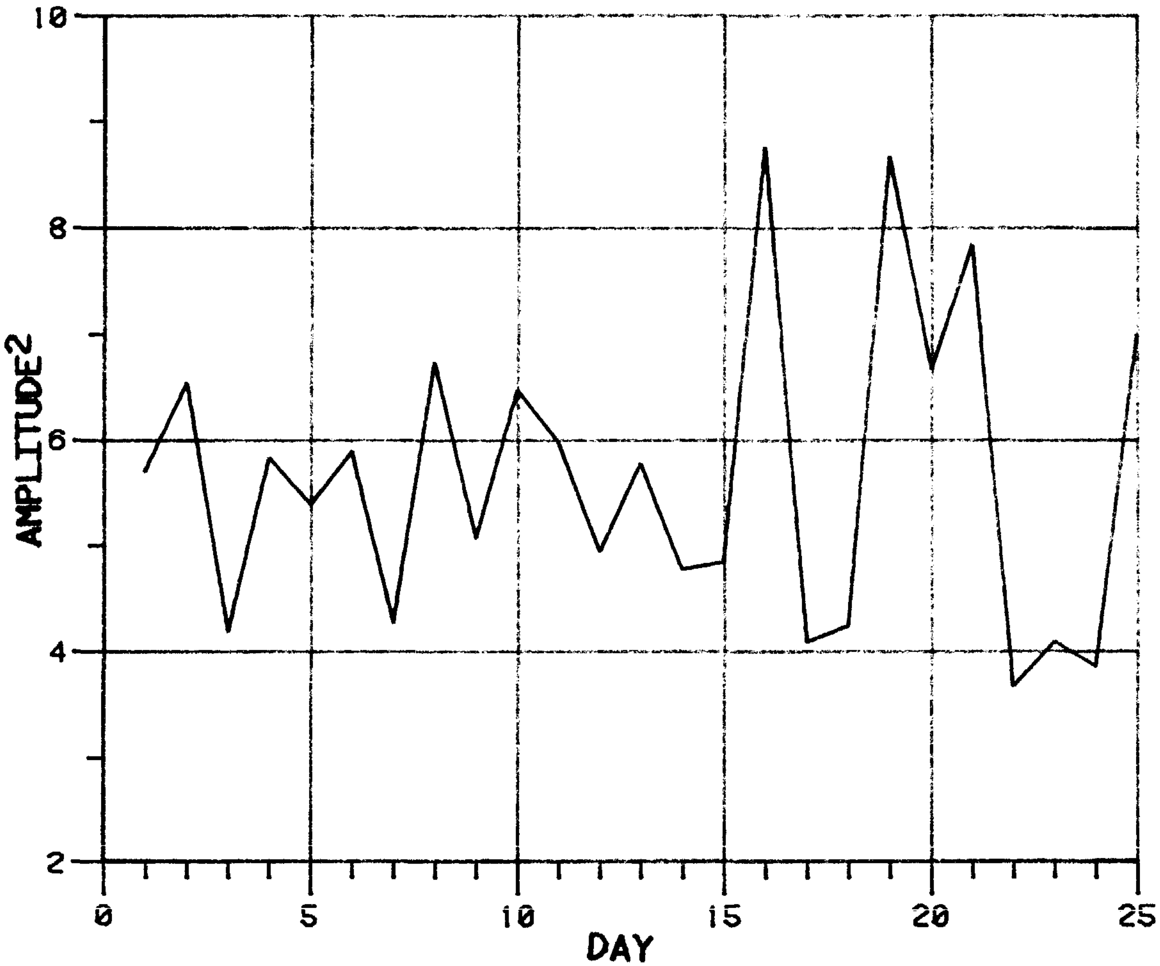
Set one C_3



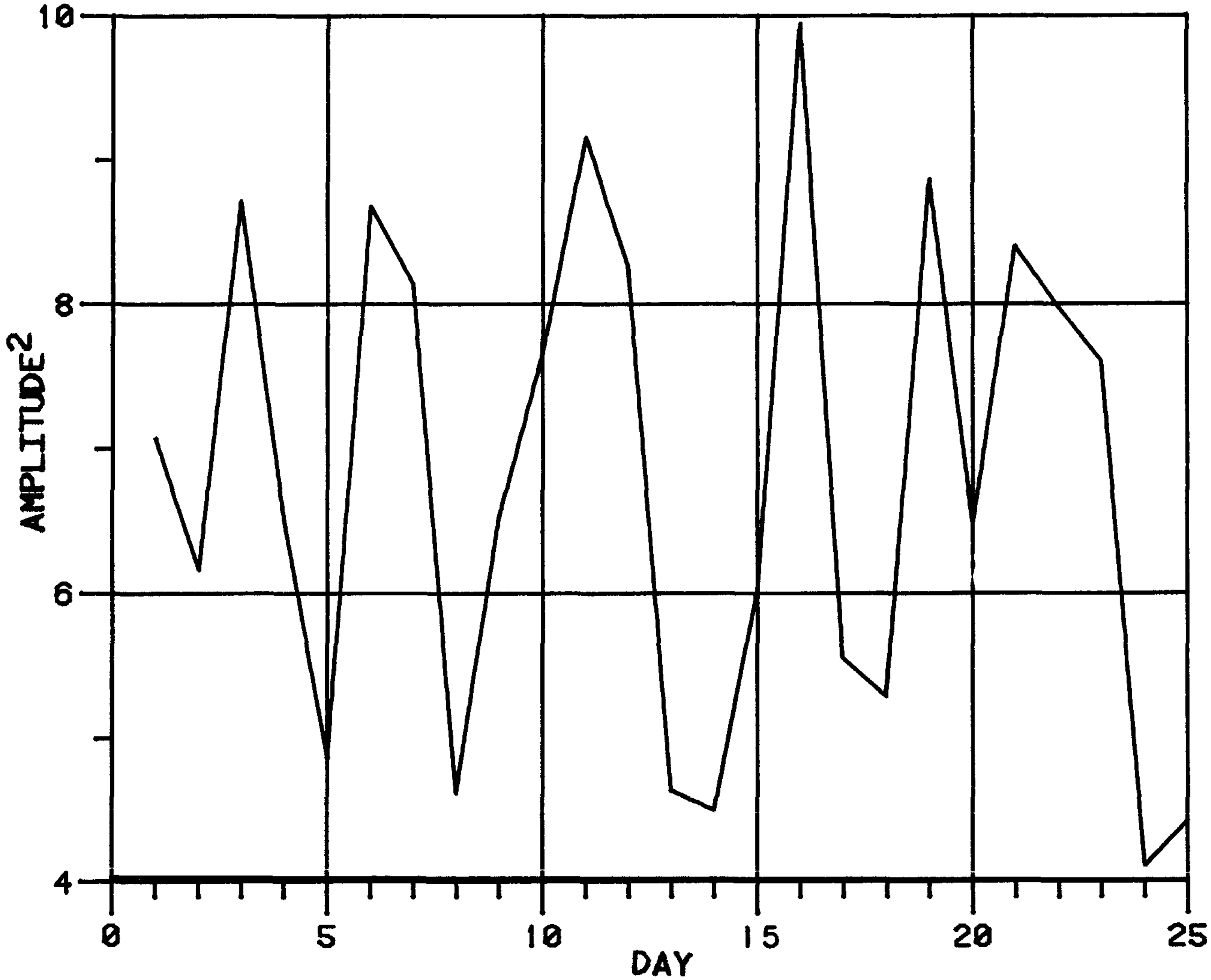
Set two C_3



Set three C_3



Set one C_4



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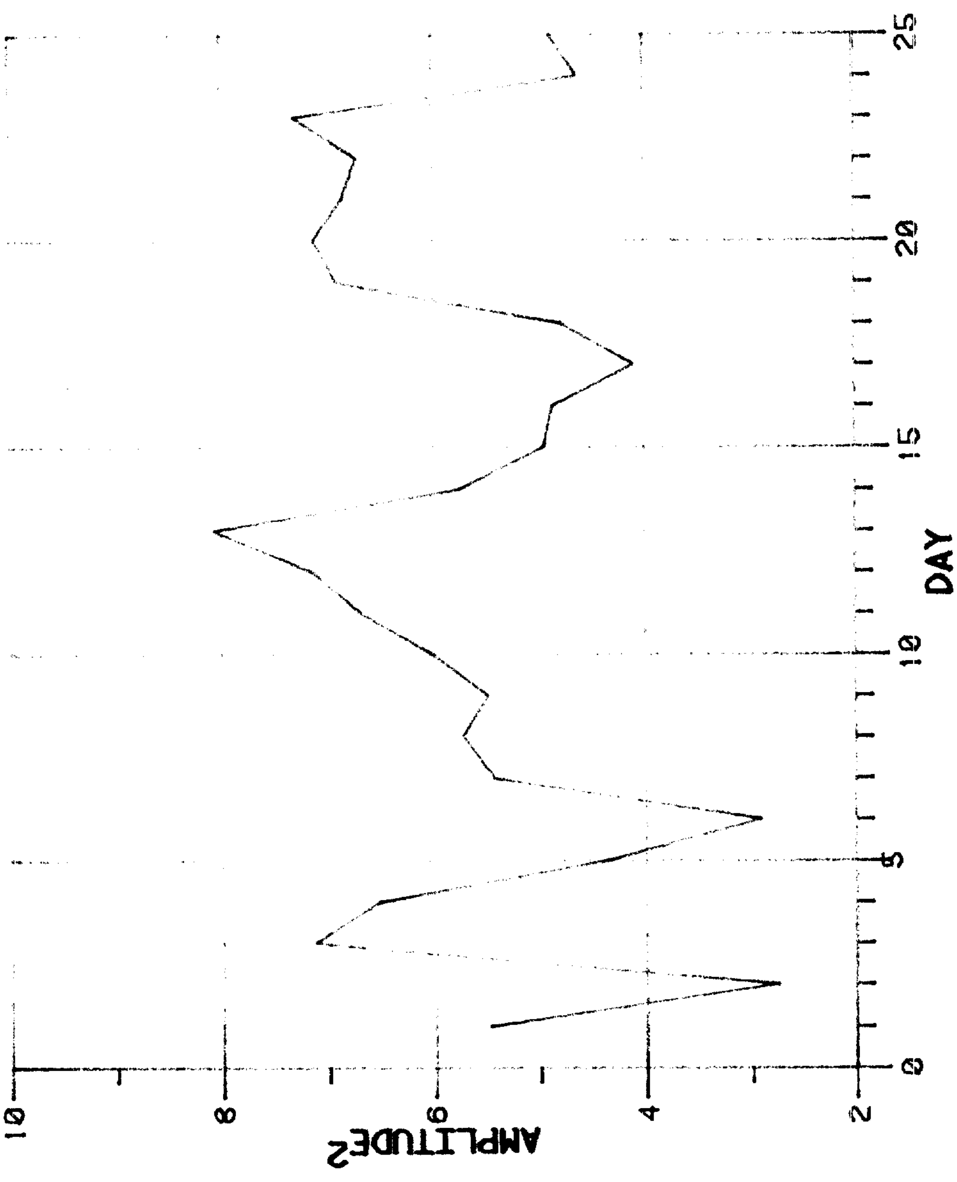

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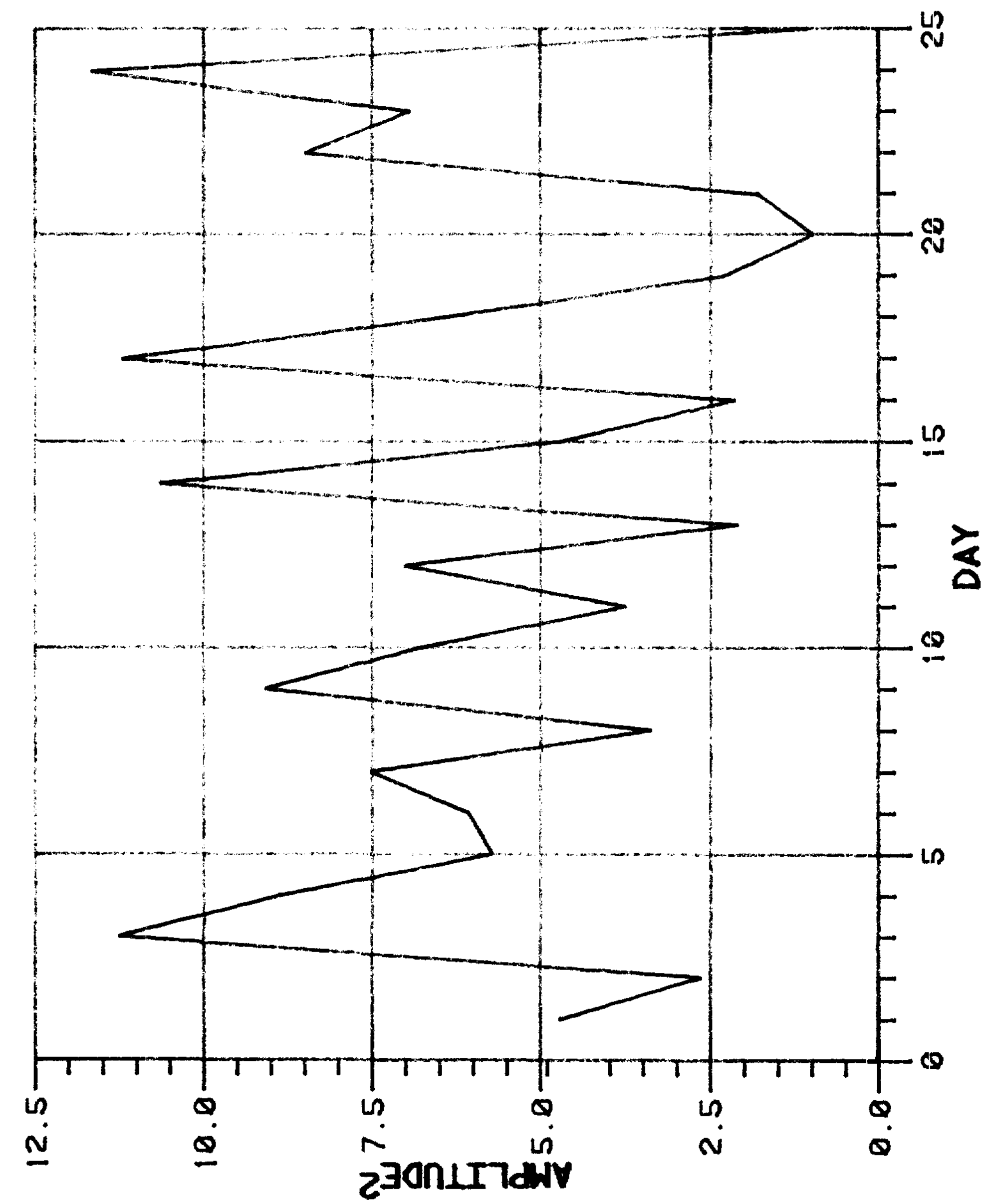
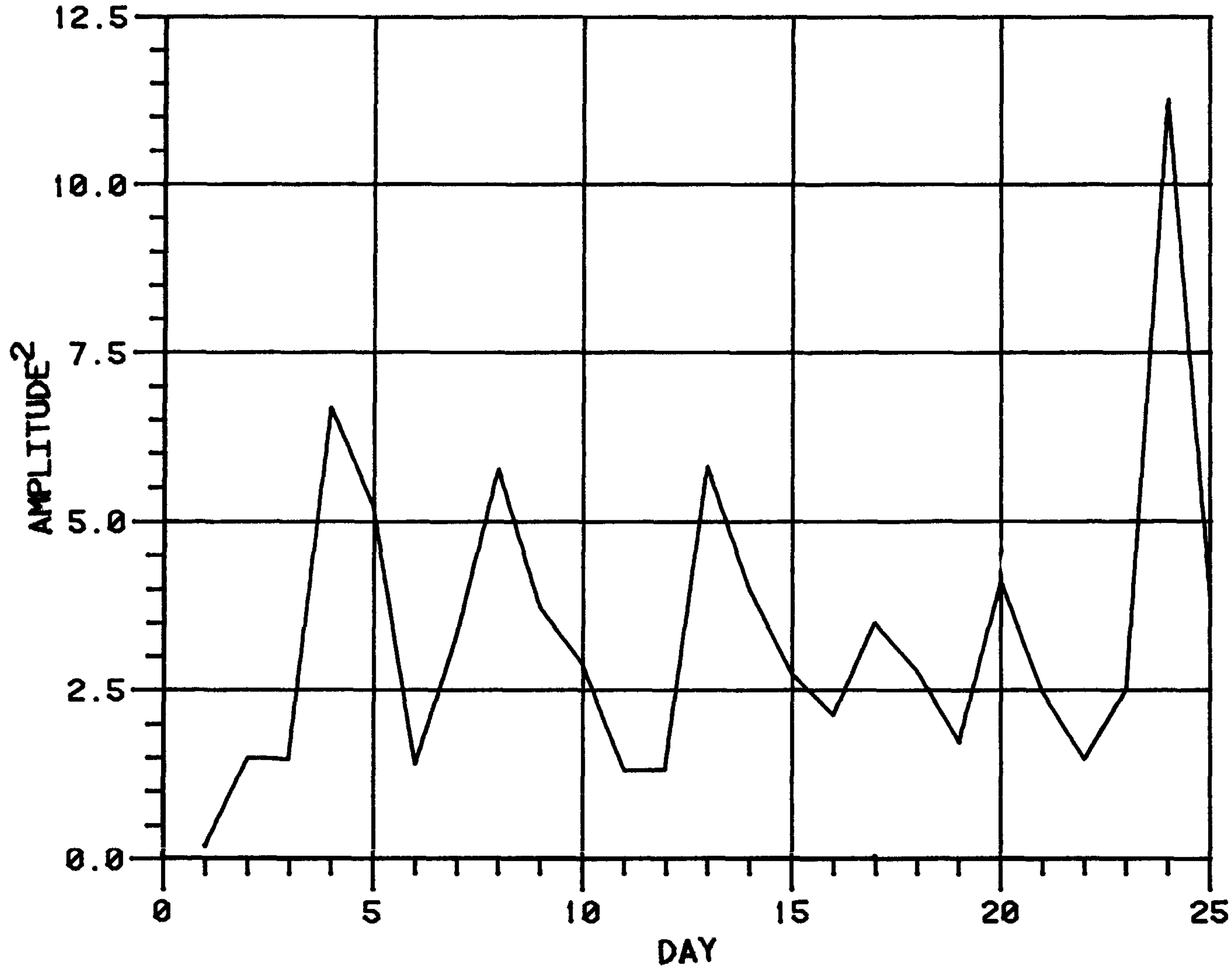
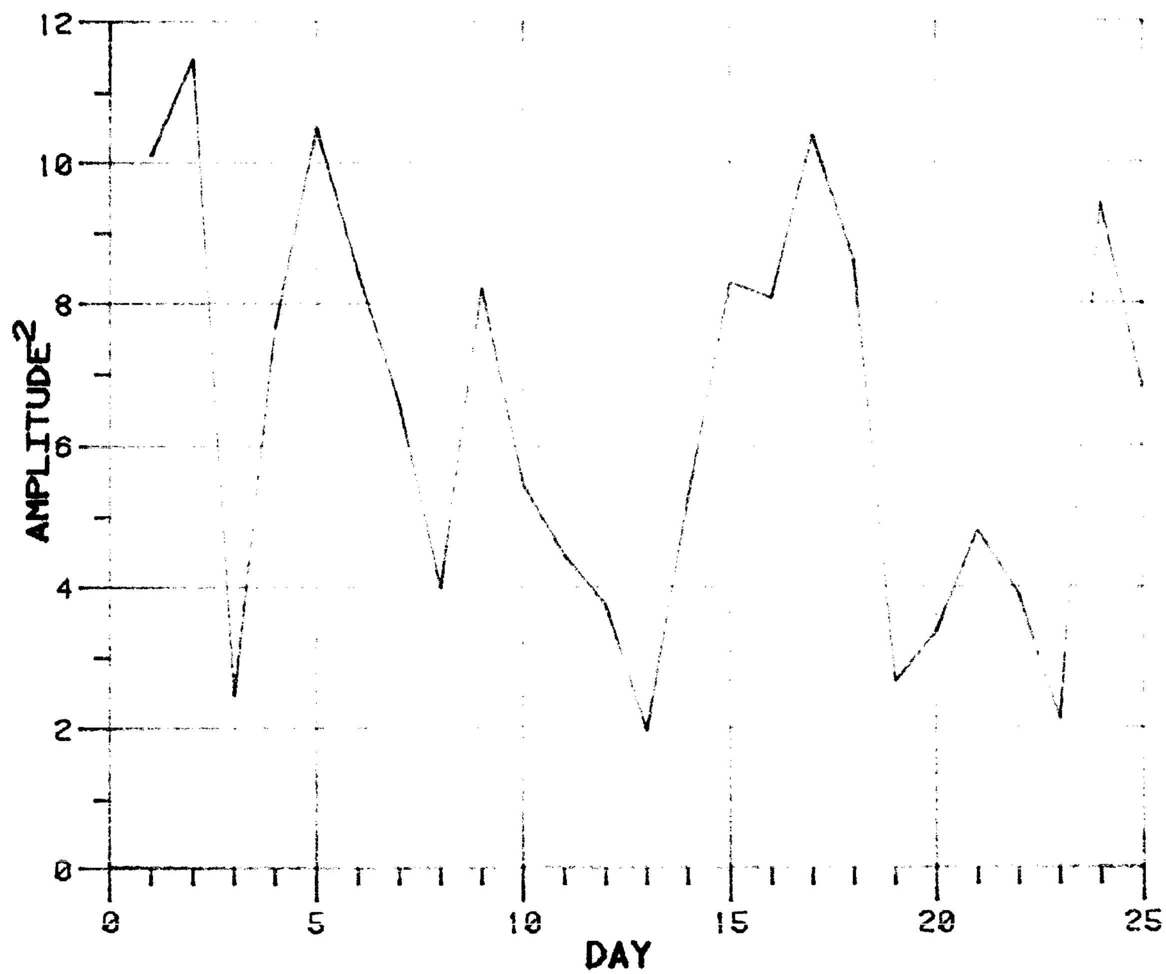


Set one C_5



Set two C_5



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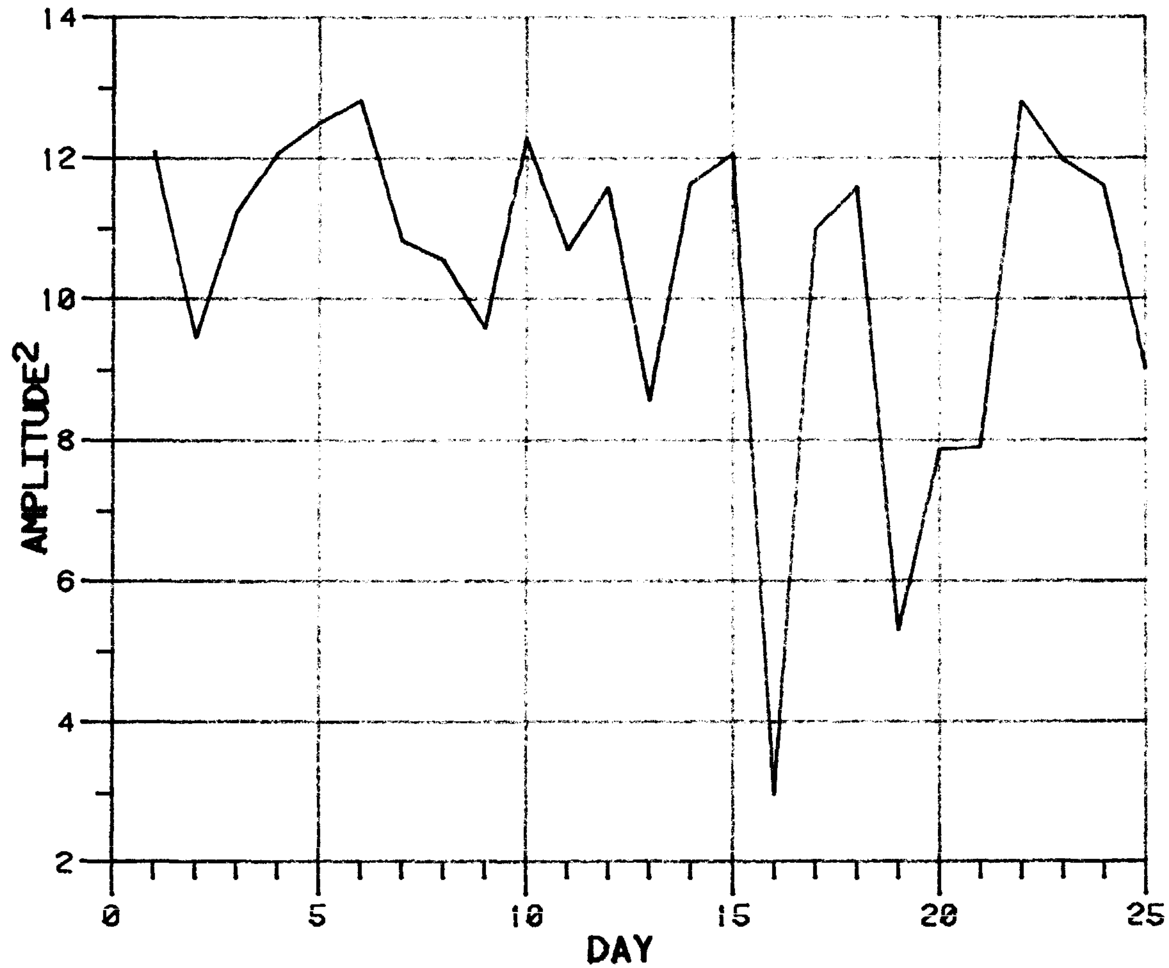
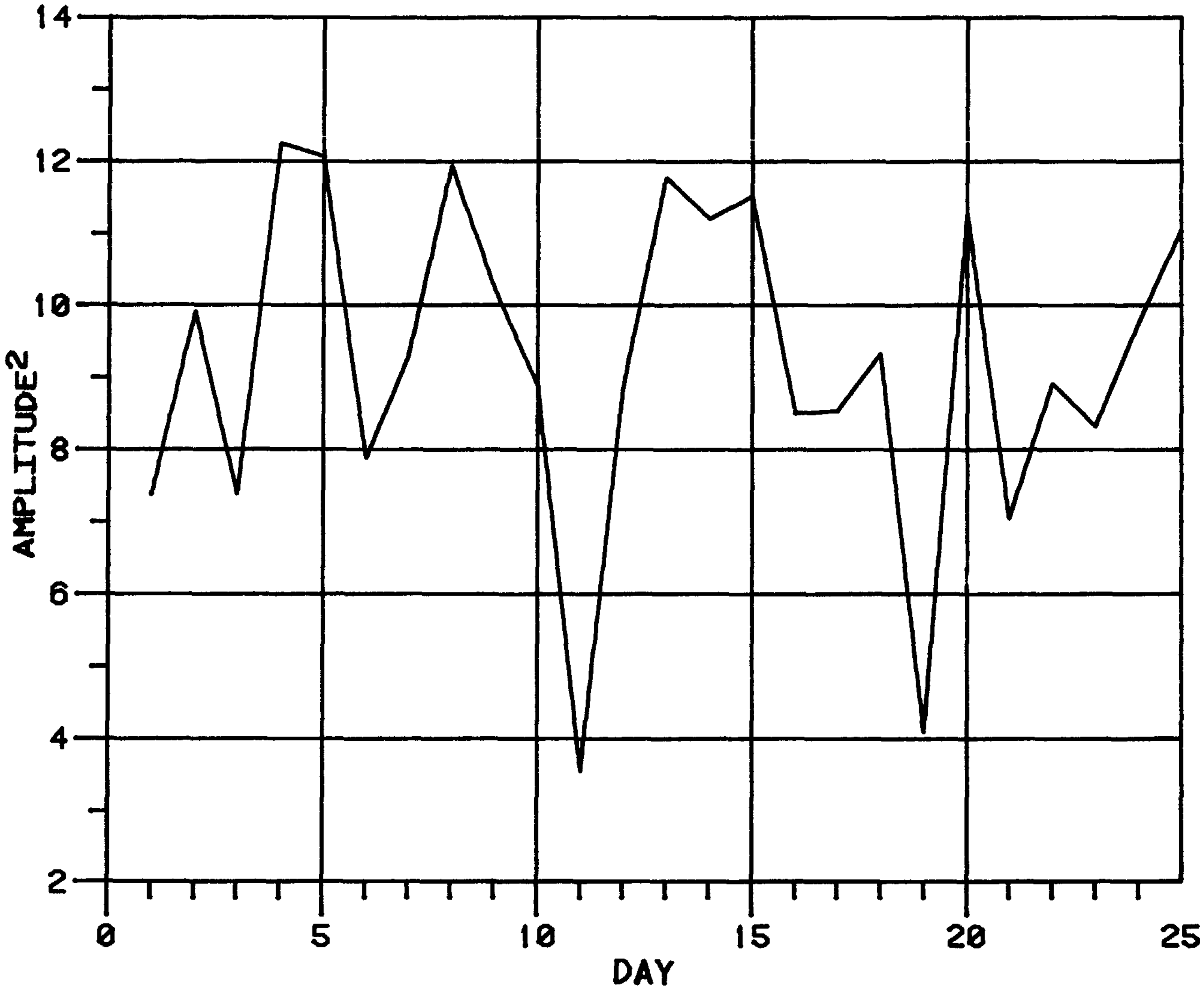
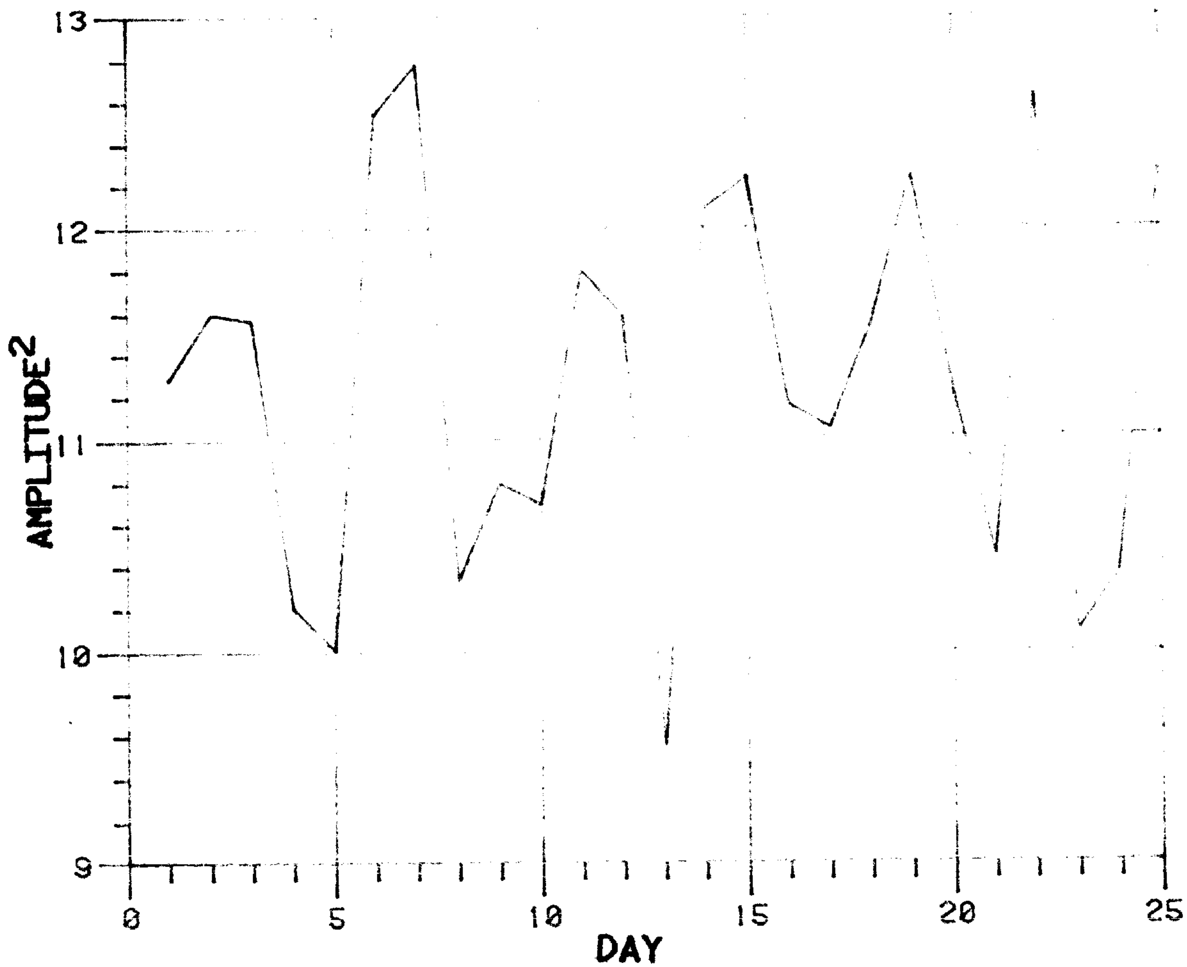


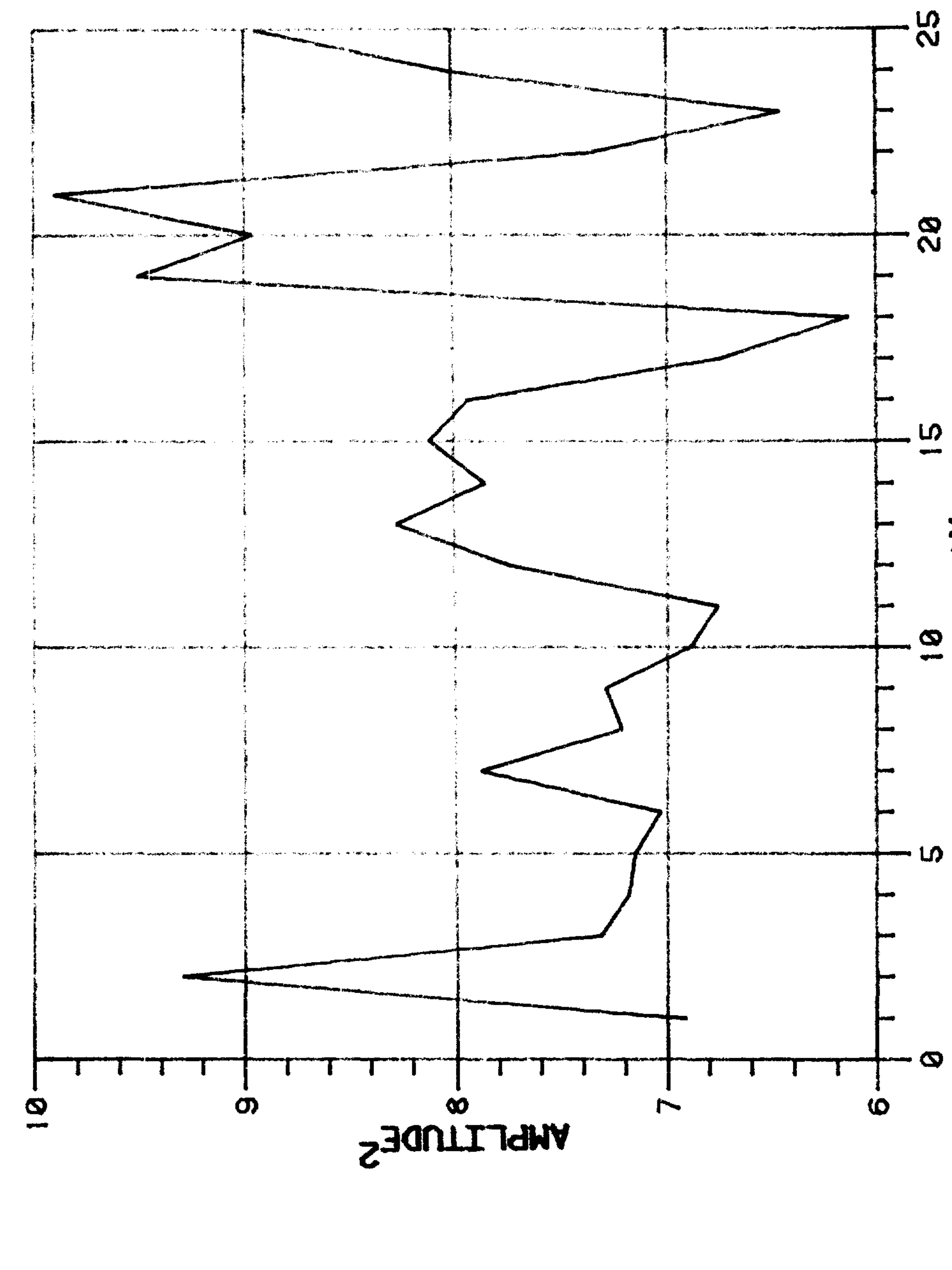
Set one C_6



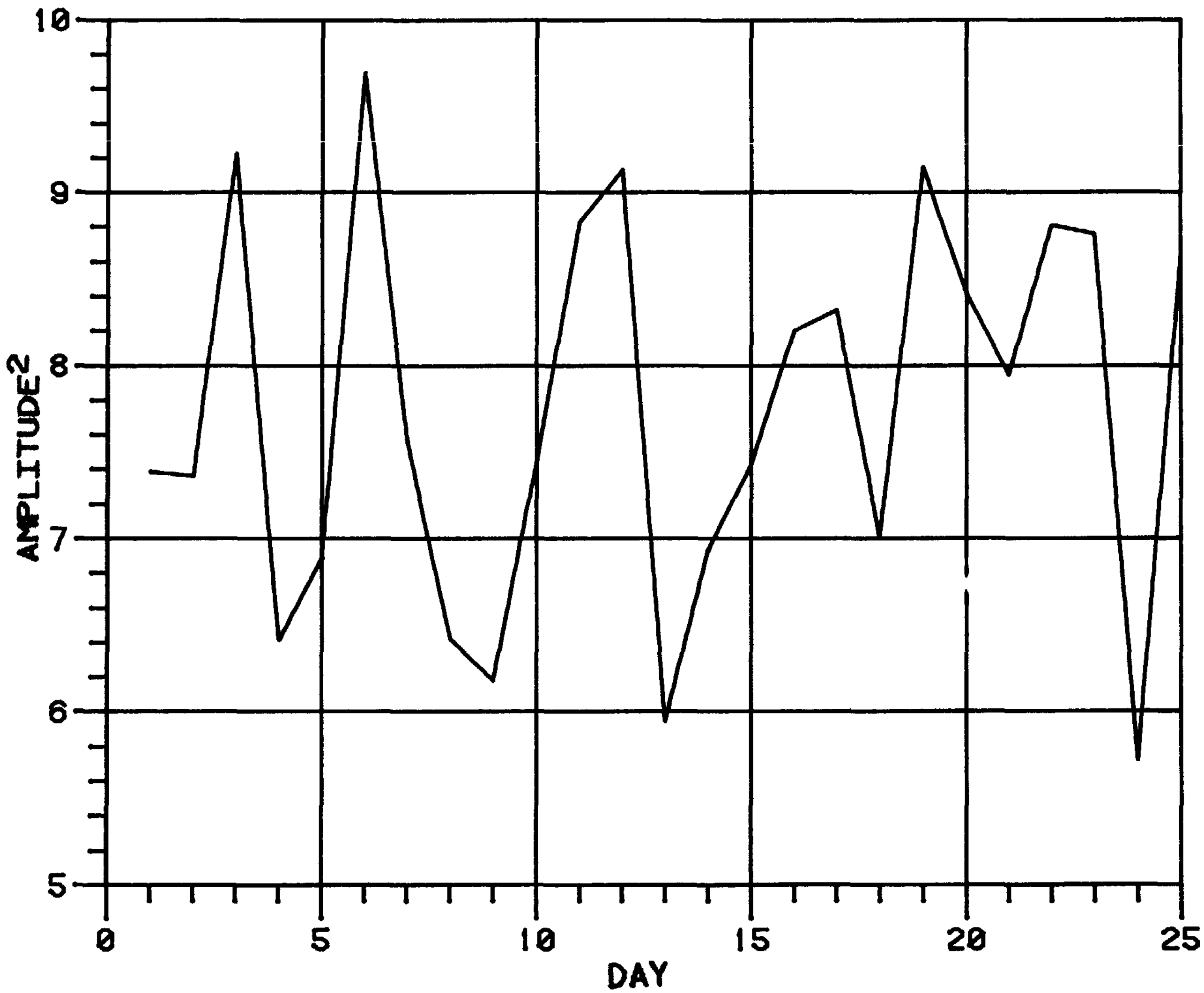
Set two C_6



Set three C_6



Set one C_7



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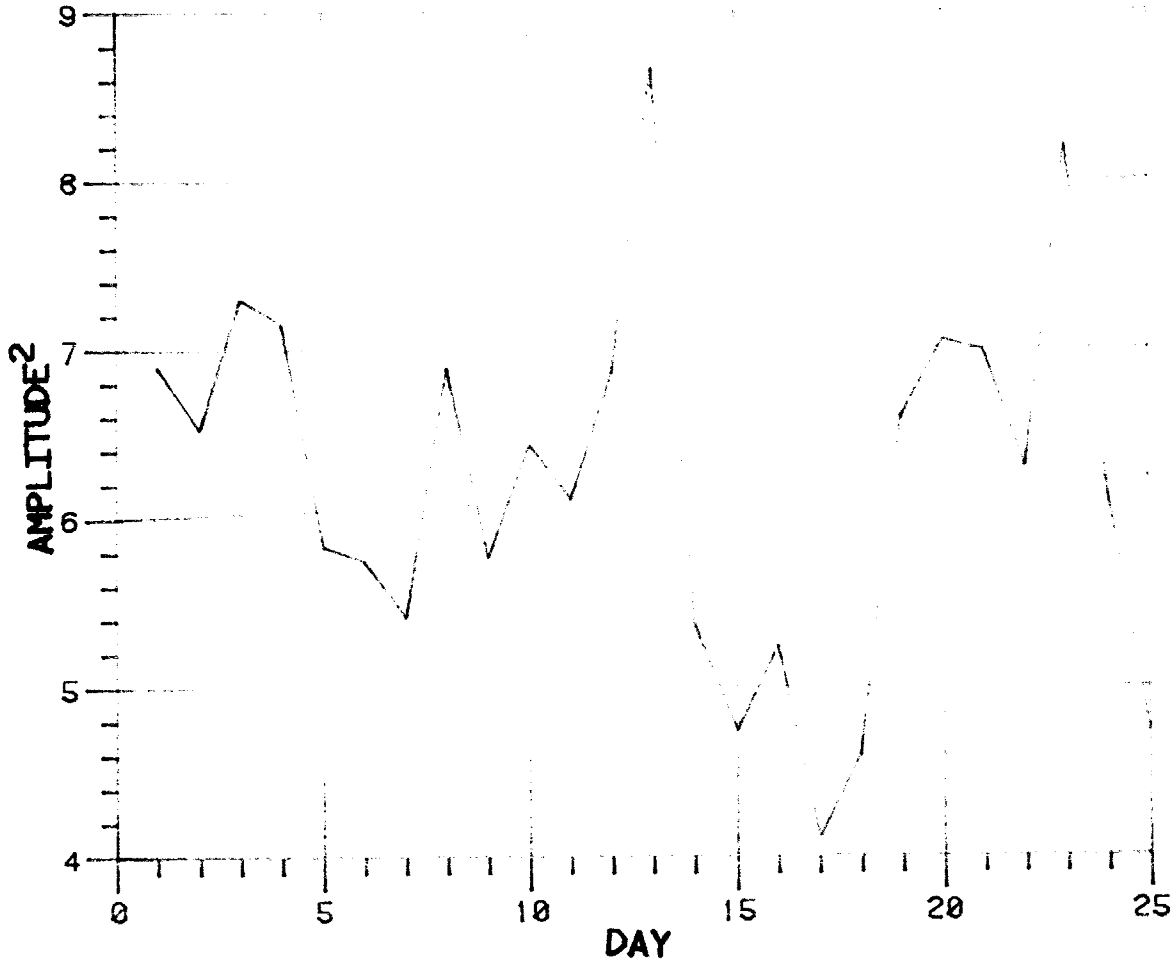

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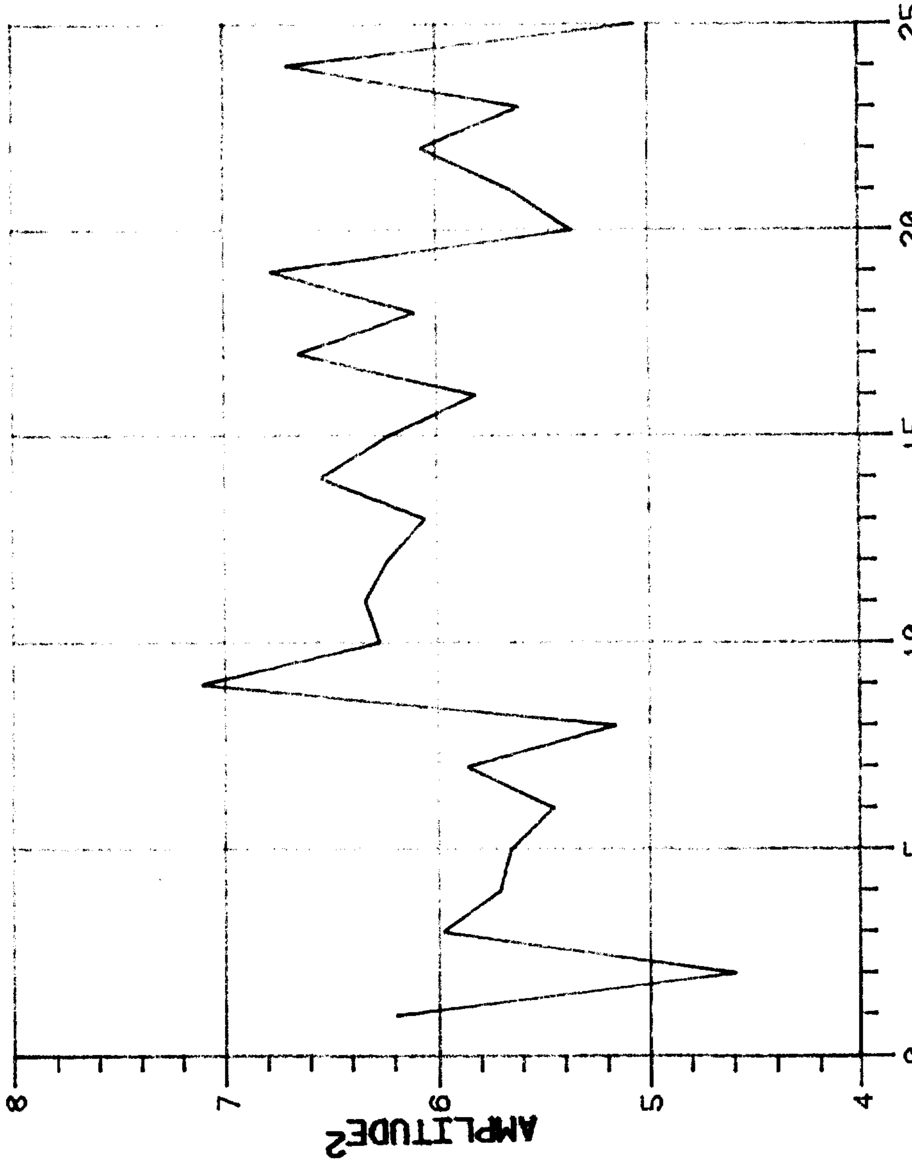
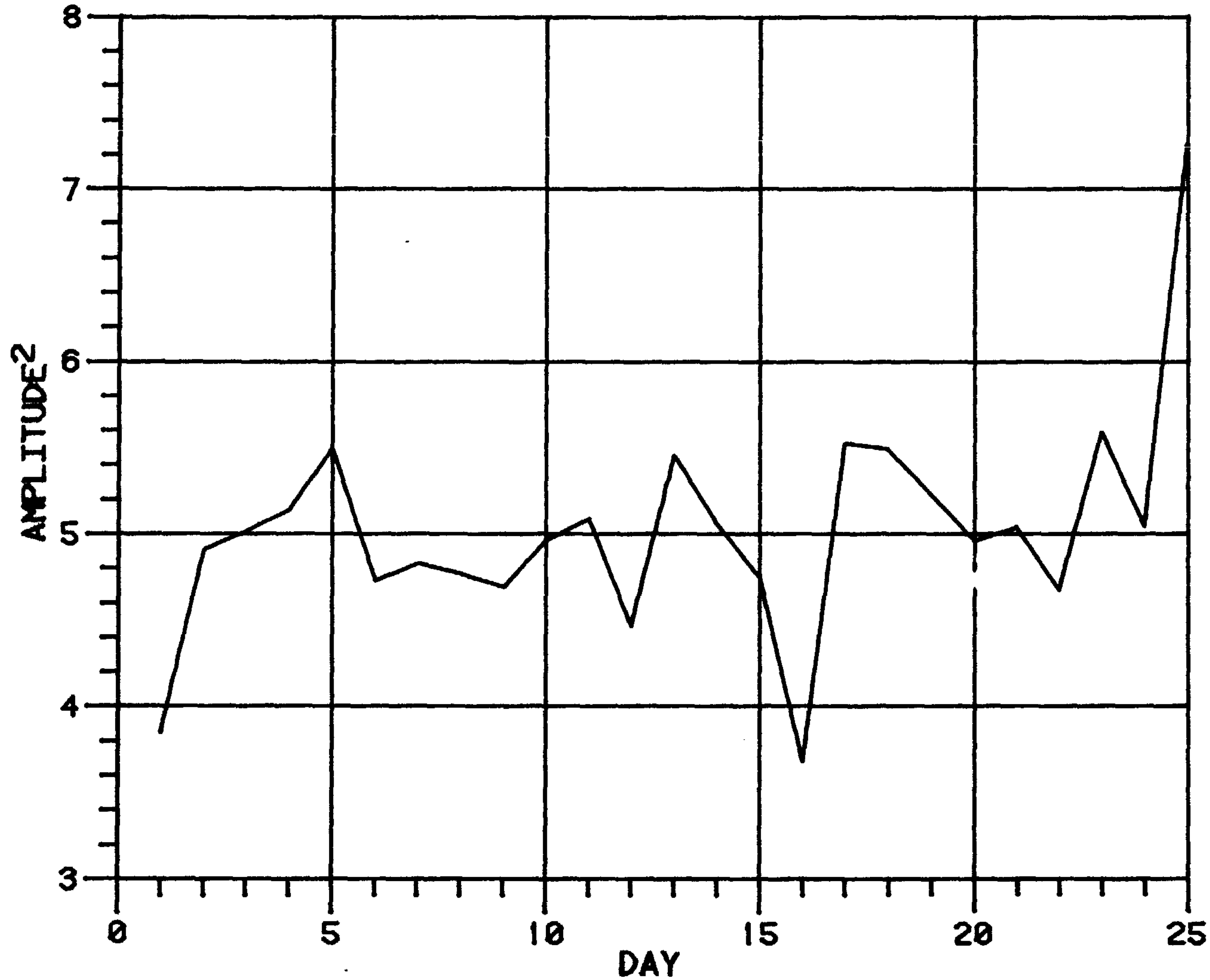


Set one C_8



Set two C_8